Appendix A: The Knowledge Base in MoST – Tasks and Activities

Appendix A kan downloades som pdf-fil fra
www.grundvandskortlægning.dk eller
www.vandmodel.dk

The MoST Knowledge Base was produced in 2006 by the project Harmonising Quality Assurance in model based catchments and river basin management (HarmoniQuA) which was partly funded under EU's FP5 (Contract EVK1-CT2001-00097)

http://www.harmoniqua.org

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Introduction to the Knowledge Base in MoST

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., 2005) 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.

Quality Assurance guidelines

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., 2000; Scholten and Groot, 2002) 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 by addressing bad practice issues such as careless handling of input data, insufficient calibration and validation, and model use outside its intended scope (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).

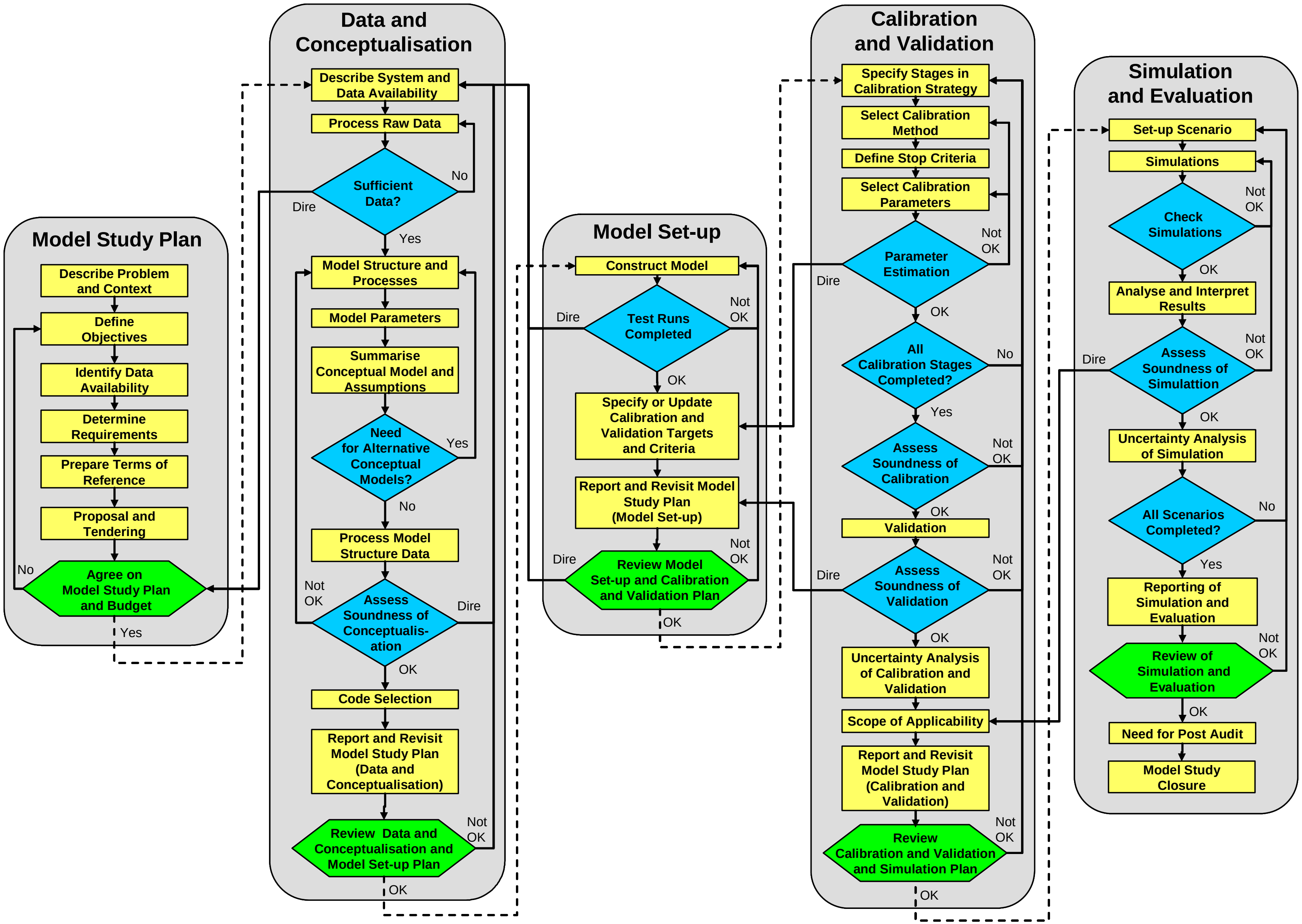
MoST and Quality Assurance (QA)

The software tool MoST, with its associated knowledge base, has been developed by the HarmoniQuA project (Refsgaard et al., 2005; Scholten et al., 2005) to provide QA in modelling through guidance, monitoring and reporting. As defined in HarmoniQuA: *"Quality Assurance (QA) is 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 NRC (1990) definition includes the organisational, technical and scientific aspects, but also the need to build consensus among the organisations concerned.

Structure and guiding principles of the Knowledge Base (KB)

The modelling process as defined by HarmoniQuA is central to MoST and the structure of its Knowledge Base (KB). The modelling process has been decomposed into five steps. The five-step system is shown in the flowchart (see figure below). 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 socio-economics), 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.


Model Study Plan
Describe Problem and Context
Define Objectives
Identify Data Availability
Determine Requirements
Prepare Terms of Reference
Proposal and Tendering
Agree on Model Study Plan and Budget
No
Yes
Data and Conceptualisation
Describe System and Data Availability
Process Raw Data
Sufficient Data?
No
Dire
Yes
Model Structure and Processes
Model Parameters
Summarise Conceptual Model and Assumptions
Need for Alternative Conceptual Models?
Yes
No
Process Model Structure Data
Assess Soundness of Conceptualis-ation
Not OK
Dire
OK
Code Selection
Report and Revisit Model Study Plan (Data and Conceptualization)
Review Data and Conceptualisation and Model Set-up Plan
Not OK
OK
Model Set-up
Construct Model
Test Runs Completed
Dire
Not OK
OK
Specify or Update Calibration and Validation Targets and Criteria
Report and Revisit Model Study Plan (Model Set-up)
Review Model Set-up and Calibration and Validation Plan
Dire
Not OK
OK
Calibration and Validation
Specify Stages in Calibration Strategy
Select Calibration Method
Define Stop Criteria
Select Calibration Parameters
Parameter Estimation
Dire
Not OK
OK
All Calibration Stages Completed?
No
Yes
Assess Soundness of Calibration
Not OK
OK
Validation
Assess Soundness of Validation
Dire
Not OK
OK
Uncertainty Analysis of Calibration and Validation
Scope of Applicability
Report and Revisit Model Study Plan (Calibration and Validation)
Review Calibration and Validation and Simulation Plan
Not OK
OK
Simulation and Evaluation
Set-up Scenario
Simulations
Check Simulations
Not OK
OK
Analyse and Interpret Results
Assess Soundness of Simulattion
Dire
Not OK
OK
Uncertainty Analysis of Simulation
All Scenarios Completed?
No
Yes
Reporting of Simulation and Evaluation
Review of Simulation and Evaluation
Not OK
OK
Need for Post Audit
Model Study Closure

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, stakeholders and the public.
- There are many feed back loops, some technical involving only the modeller, and others that may require a decision before doingcostly additional work.
- The KB allows performance and accuracy criteria to be updatedduring the modelling process. In the first step the water manager'sobjectives and requirements are translated into performancecriteria that may include qualitative and quantitative measures.These criteria may be modified during the formal reviews ofsubsequent steps.
- Emphasis is put on *validation schemes*, i.e. tests ofmodel performance against data that have not been used for modelcalibration.
- *Uncertainties* must be explicitly recognised and assessed(qualitatively and/or quantitatively) throughout the modellingprocess.

MoST supports multi-domain studies and working in teams ofdifferent user types (water managers, modellers, auditors, stakeholders and members of the public). It contains an interactiveglossary that is accessible via hyperlinked text. The keyfunctionality of MoST is to

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

Organisational requirements for QA guidelines to be effective

Modelling studies involve several parties with differentresponsibilities. The key players are modellers and water managers,but often reviewers, stakeholders and the general public are alsoinvolved. To a large extent the quality of the modelling study isdetermined by the expertise, attitudes and motivation of the teamsinvolved in the modelling and QA process.

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

Scientific documentation

Documentation of the design and guiding principles of theKnowledge Base can be found in the following publications:

- Refsgaard and Henriksen (2004): Scientific philosophical basis, terminology and guiding principles.
- Refsgaard et al. (2005): State-of-the-art of modelling guidelines and outline and key elements of Knowledge Base.
- Scholten et al. (2005): Development of Knowledge Base andMoST.
- Henriksen et al. (2009): The role of public participationin relation to QA.

KB and MoST terminology

Terms used in the KB and MoST are tabulated below:

Term	Definition	Abbreviation
Activity	Each task in MoST is decomposed into a number of activitiescomprising descriptions of things to be done within the specifictasks.	-
Auditor	A person that is conducting some kind of review of a modellingstudy. The review may be more or less comprehensive depending onthe requirements of the particular case. The auditor is typicallyappointed by the water manager to support the water manager tomatch the modelling capability of the modeller. The auditor maybelong to the water manager's organisation or to an independentorganisation. The task of the auditor should be distinguished from internalreviews, which the modeller's organisation often carry out as partof its internal quality assurance procedure. The reviews performedby the auditor are done over and above any internal reviews thatthe modeller may carry out.	AU
Client	Synonym of Water Manager	-
Consultant	Synonym of Modeller	-
Method	A description of a methodology for carrying outan activity, possibly with links to supporting tools.	-
Modeller	A specialist who undertakes the technical modelling activity. Amodeller should have expert knowledge of both the issue and thesound model modelling approaches. The modeller should present andinterpret the model outputs to the	MO

	water manager and to thestakeholders. The modeller is the counterpart of the water manager. If themodeller and the water manager belong to different organisationstheir roles will typically be denoted consultant and client,respectively.	
Public	The public is composed of partners that are not directlyinvolved (as modeller, manager or auditor) in a modelling study butthat have a legitimate interest in the modelling results. Thepublic may typically be either interest groups/stakeholders or thegeneral public.	PU
Stakeholder	The interested parties, i.e. those with a stake in the watermanagement issue, either their interest is in exploiting orprotecting the resource. Stakeholders include the following different groups: (i)competent water resource authority; (ii) interest groups; and (iii)general public. The water manager typically belongs to one of thefirst two groups.	SH
Step	MoST decomposes the modelling process into five major steps and48 tasks. The five steps are: 1. Model Study Plan 2. Data and Conceptualisation 3. Model Set-up 4. Calibration and Validation 5. Simulation and Evaluation	-
Surface water quality domain	The surface water quality modelling domain comprises waterquality processes in all surface water elements such as: • River systems including flood plain, lakes and reservoirs • Estuaries and coastal waters The surface water quality domain in MoST corresponds to thewater quality aspects in 'river' 'lake' 'transitional water' and'coastal water' as these terms are defined in the Water FrameworkDirective.	WQ
Task	Action to perform with a clear purpose, e.g. defining objectivesor model calibration. A task belongs to a step. A task consists ofone or more activities. Tasks can be the responsibility of one ormore roles (water manager, modeller, auditor, stakeholder, public). There are 3 types of tasks in MoST: • (normal) task: task without a decision • decision task: an authorized team member should decide whetherto continue in the process or to re-do one or more tasks • review task: a decision task in which team members withdifferent roles have to discuss what is done in the step and how tocontinue in the next step	-
Water manager	A water manager is the person or organisation responsible forthe management or protection of the water resource, and thus of themodelling study and its outcome (the problem owner). The water manager is the counterpart of the modeller. If thewater manager and the modeller belong to different organisationstheir roles will typically be denoted client and consultant, respectively.	MA

References

Henriksen HJ, Refsgaard JC, Højberg AL, Ferrand N, Gijsbers P, Scholten H (2009) Harmonised principles for public participation in quality assurance of integrated water resources modelling. Water Resources Management, 23, 2539-2554.

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

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

Scholten H, Kassahun A, Refsgaard JC, Kargas T, Gavardinas C,Beulens AJM (2005) A methodology to support multidisciplinarymodel-based water management. Environmental Modelling &Software accepted.

Van Waveren RH, Groot S, Scholten H, Van Geer FC, WöstenJHM, Koeze RD, Noort JJ (2000) Good Modelling Practice Handbook, STOWA Report 99-05, Utrecht, RWS-RIZA, Lelystad, The Netherlands,http://waterland.net/riza/aquest/(In Dutch)

Step 1: Model Study Plan

This step aims to agree on a Model Study Plan comprising answers to the questions: Why is modelling required for this particular model study? What is the overall modelling approach and which work should be carried out? Who will do the modelling work? Who should do the technical reviews? Which stakeholders/public should be involved and to what degree? What are the resources available for the project? To answer these questions the water manager needs to describe the problem to be addressed and its context. Then the role and objectives of the modelling within this context need to be described and the available data identified and described. A very important task is then to analyse and determine what are the various requirements of the modelling study in terms of the expected accuracy of modelling results and the interaction with stakeholders and/or the public. The acceptable level of accuracy will vary from case to case and must be seen in a socio-economic context. This is not usually defined by the modeller, but through a dialogue between the modeller, water manager and stakeholders/public. In this respect an analysis of the key sources of uncertainties is crucial in order to focus the study on the elements that produce most information of relevance to the problem at hand. These findings have to be described in the Terms of Reference. This document will serve as the basis for a technical and financial proposal prepared by one or, in case of competitive tendering, several potential modellers. The selected proposal is then adapted through negotiations between the water manager and the modeller to form the Model Study Plan.

1.1 Describe Problem and Context

User Type: MA

Definition

A specification of the known problem and the context of the study.

A problem has been detected. It has been decided that a modelling study could provide useful contributions towards the management decisions needed to address the problem. The first task is to analyse the problem and decide how such a modelling study might be framed. This is the responsibility of the water manager, but it is likely to require inputs from stakeholders and possibly the general public.

Activities

- Domain Description
- The Problem
- Problem Context
- Type of application (PR)
- Problem context (FF)
- Physical Processes (FF,GE,GW,HD,WQ,SE,PR)
- Physical Processes and Linkages (BI)
- Physical processes and linkages (SE)
- Model Use Appropriate?
- Model Use Appropriate? (BI)
- Socio-economic Approaches Appropriate? (SE)
- Temporal and Spatial Scales
- Catchment Description (PR,SE)
- Prepare Stakeholder Involvement Plan (SIP)
- Prepare Stakeholder Analysis
- Interaction and Communication

Introduction to activities

1. The water manager (client) should perform this task and later in 'Agree on Model Study Plan and Budget' he/she should agree it with the modeller. User Type: MA
2. The water manager (client) should perform this task and later in 'Agree on Model Study Plan and Budget' he/she should agree it with the modeller.Guidance is restricted to ecological models with a similar or narrower geographical scope to other types of model (GW, PR, WQ). This includes models to be set up at the river basin, catchment or sub-catchment level. However, plenty of ecological

modelling studies are undertaken at the regional scale, in order to make local predictions. This is often necessary because to create useful predictive models, data must be utilised from a wide spatial area. User Type: MA

3. In contrast to hydrological models (such as groundwater models), it is difficult to find operational socio-economic models at the river basin level. Most SE models are aggregated at the regional or national level without relation to local conditions in river basins. Therefore, incorporation of SE aspects firstly requires validated hydrological models, to which SE tools are to be linked. Important tools are water demand forecasting models, cost-effectiveness analysis (CEA), cost-benefit analysis (CBA) and multi-criteria analysis (MCA). User Type: MA

Domain Description

User Type: MA

Describe whether the problem belongs to single or multiple domains. The knowledge base provides dedicated guidance for the following domains:- Groundwater- Precipitation-runoff (incl. diffuse pollution)- Hydrodynamics (incl. sediment and morphology)- Flood forecasting - Surface water quality- Biota (ecology)- Socio-economicsIt is important to recognise that models of some domains will have to include elements from other domains. For example, Surface water quality modelling will require that Hydrodynamics modelling is also carried out. Similarly, applied ecological models will generally be linked to another domain, commonly Surface water quality or Hydrodynamics. Finally, the Flood forecasting domain is mainly concerned with real-time aspects. It should typically be used together with the Precipitation-runoff and/or the Hydrodynamics domains.

The Problem

User Type: MA

Based on documents and other information, a summary of the problem and broad objectives should be written as part of the Terms of Reference.

Problem Context

User Type: MA

Summarise the context of the current problem and specify:- The complexity of the job (basic, intermediate, comprehensive)- The importance of making a decision on the current problem (international, national, local, European, forced by law, etc.)- Other contextual information (e.g. research, policy making)Questions that may be considered include:What pressures are causing the stresses, e.g. abstractions, river channel engineering, diffuse/point source pollution?What drivers are causing the pressures, e.g. development, urbanisation, flood defence?With regard to the socio-economic domain specify if the study refers to water policies (e.g. water pricing, subsidies and mandatory regulations), to changes in the water demand of different water users, to changes in the infrastructures for water supply and wastewater disposal, to the costs and economic benefits of water management strategies, to economic optimisation procedures (e.g. cost-effectiveness analysis) or to the impacts of water management decisions on economic sectors (such as agriculture, industry, households).It may be beneficial to adopt the DPSIR framework (linking Drivers, Pressures, States within the system, Impacts and Responses). This is a general framework designed for organising information on the state of the environment. It assumes a cause-effect relationship between interacting components of systems. Its use will enhance comparability of reported information. Through adopting its logic and using common language the state of the environment report should be easily understood.

Physical Processes

User Type: MA

Describe the processes (physical, geo-chemical, ecological and socio-economical) which are relevant to the current problem.

Model Use Appropriate?

User Type: MA

The client, with advice from a modelling expert, decides on whether a model is the best tool to solve the problem.Sometimes the use of a model does not contribute to a better understanding of a system nor assist in problem solving. This is especially true when there are no data and there are no resources (time and money) for data collection. Alternative approaches may be better or may even be the only way to assess the problem. The current knowledge base on modelling does not provide guidance for these alternative approaches.

Temporal and Spatial Scales

User Type: MA

Describe the time horizon (period over which predictions should be made) and time resolution (time steps in which characteristic processes vary significantly). The same applies for the spatial resolution. Problems arise when some processes are fast compared to others or when spatial scales of the processes differ significantly.For temporal resolution, time-steps ranging from less than one hour to a year may typically be used depending on the type of model application. Continuous or event-based modelling may be considered. For real time applications lead times of forecasts should be considered.Spatial resolution may be lumped, semi-distributed or distributed.This activity should account for the perception of the client on how models, in general, can be applied to solve the type of problem. Later on, the clients view should be 'merged' with the modeller's view to come to a 'wanted' (by the client) and 'realistic' (by the modeller) outline of ideas that will be used in the development of a conceptual model.The client must be clear on these matters to avoid misunderstanding during the whole model study.

Prepare Stakeholder Involvement Plan (SIP)

User Type: MA

Decide on how and to what extent stakeholders and the general public will be involved in the modelling study.The following should be considered: - What level of public participation is required (information supply, consultation, active involvement etc.)? - Why is public participation required? - Who should we involve? - When should we involve them? - How do we involve them? The Stakeholder Involvement Plan should comprise, but not necessarily be limited to, the following objectives: - Developing a common understanding of problems or concerns- Defining goals, aims, principles and characteristics of public participation- Defining team roles and responsibilities- Maintaining a list of stakeholders- Evaluating the group's interest and responsibilities (if different authorities are involved)- Forming working groups (professional stakeholders and/or groups of citizens) and planning public/individual meetings- Selecting a facilitator(s) for different public and professional stakeholder groups- Creating mission statements (terms of reference, rules and responsibilities) for all groups- Outlining the time schedule for group work and meetings to review milestones- Describing resources for implementing the Stakeholder Involvement Plan- Describing initiatives for informing general public and stakeholders- Defining public information to be entered in monitoring tool and by whomA stakeholder analysis will be necessary both for the evaluation of degree of common understanding of problems and the identification of relevant stakeholder interests and responsibilities (see Activity Stakeholder analysis).Forming working groups, selection of a facilitator, mission statements and initiatives for information of general public and stakeholders will require selection of proper interaction and communication tools (see Activity Interaction and communication).The draft SIP should be included in the Terms of Reference, discussed with the modeller and subsequently included in the Model Study Plan as a separate chapter.

Prepare Stakeholder Analysis

User Type: MA

A stakeholder analysis aims at identifying and assessing the importance of key people, groups of people, organisations, or institutions that may significantly influence the success of the project. A stakeholder summary table should be established. It should include, but is not necessarily limited to, the following information:- List the relevant stakeholders- Attitude and confidence of stakeholders- Plan strategies and level of involvement of each stakeholder: information, consultation or active involvement- Kind of information the stakeholder will need- Need for involvement of the stakeholders in the planning process

Applicable methods:

- Stakeholder Summary Table

Interaction and Communication

User Type: MA

Participatory processes require instruments/tools with focus on interaction, communication and participation. Can be designed in several concrete forms using GIS, websites, games etc. To put into action the different communication means is no hard core science. Often these means are close to each other. All means are explained in more details in the guidance document. Public participation, Annex I (EC, 2003).The formulation of a rough communication strategy will take place in an early stage of the route, preferably during the starting phase. At the entering of every review step the plan will be adjusted, since the role and the dedication of the actors can change. The communication strategy can be used for this as a working schedule and can help in keeping an overview of all communication activities. Naturally a flexible process also demands a flexible communication: a continuous alertness for developments within the project which make communication possible or necessary. Interaction and communication tools (see method Interaction and communication ABC) may be used for selection of proper ICT-tool.The basis of the planning is the grouping of the actors after involvement. At this inventory, actors should be grouped into four main categories: - Co-operators- Co-thinkers- Co-knowers- Deciders(see method Actors grouping)

Applicable methods:

- Interaction and Communication ABC
- Actors grouping

Other task aspects

Sensitivities and Pitfalls

1. **The Importance of a good Problem Description** : The biggest risk of not describing properly the problem at hand, is that sometimes another problem will be solved in the model study. The client should be sure the modeller understands and agrees on the problem description. User Type: MA
2. **Public Participation** : Carried out properly, public participation offers the opportunity to build trust and capacity, empower people by starting a dialogue and improving openness, expand the limits of understanding and improve the accountability of stakeholders. It can also make use of local and citizen knowledge not known by the authorities, encourage diverse perspectives and enable a better evaluation of the issues.But public participation could also be weakened by a lack of resources (time, money, staff), a lack of rules for participation, a lack of in-depth involvement of authorities and a lack of professional supervision of the stakeholder involvement process. Public participation can be threatened if the public thinks that the process is a formality (that minds are already made up) or if a vocal minority dominates meetings User Type: MA
3. **Interdisciplinary Approach** : When dealing with interdisciplinary river catchment modelling involving economists, ecologists and hydrologists, working together and communicating with stakeholders and the general public, a number of challenges can be foreseen: -Problems with academic territories (different disciplines effectively speak different languages, defence of own territory and domains

operate at fundamentally different levels of spatial and temporal aggregation). Also, there are likely to be differences in the expectations of the model by members of the modelling team from different disciplines (e.g. errors in modelling ecology are likely to be greater than errors in modelling hydrology).- The illusion of the technique (underlying models and datasets are rather complex for users, effort to reflect real world led to greater refinements, causing the models to become harder to comprehend and maintain; there may also be lack of spatial and temporal data coverage and knowledge)- Shelfware (some practitioners and policy makers are extremely sceptical about the value of models and their usage and may not at all accept need for catchment approach or spatial connectivity). User Type: MA

4. **Chained Models** : Surface water quality and ecological models are often used in chains of models. In such cases it is important to ensure that the 'underlying domains' (e.g. hydrodynamics in case of surface water quality) are simulated so that it meets the requirements of the domains that are at the end of the chain. As an example the spatial/temporal resolution and quality of the model outputs must be suitable input to ensure the requirements of the water quality and/or ecological models. User Type: MA
5. **Interdisciplinary Approach** : Ecological modelling often requires an interdisciplinary approach. Therefore, modellers need support from a multi-disciplinary team. If this is not the case then solutions may be sought from an inappropriate domain. User Type: MA
6. **Simple Models** : It is advisable to keep ecological models simple as many processes are poorly understood. Complex ecological modelling should only be undertaken by experienced modellers. User Type: MA
7. **Public Participation - Active Involvement** : Many examples of insufficient outcome of modelling projects during the last decade are related to inappropriate stakeholder and general public participation e.g. by use of ambiguous terminology and a lack of understanding between key players, miscommunication, confusion on how to use model results in decision making and insufficient consideration of economic, institutional and political issues. Active involvement and negotiation is not incorporated or covered by MoST /HarmoniQuA at the moment, because such processes can not be ruled by a fixed scheme or by a flowchart where there is a build in hierarchy of the order of tasks, and more or less fixed feed back routes. Experimental learning, and active involvement would require much more flexible routes (switching between different methods) depending on problems and context.There are no protocols in HarmoniQuA for describing the way groups works together, including factors such as concurrency, integrity and social relationship. Use of HarmoniQuA for more extended forms of public participation e.g. active involvement and social learning is not supported by the tool. There is a potential for using MoST for such purposes, but it will require development of a new knowledge base dedicated to active involvement. HarmoniQuA assesses a procedure and provides a tool (MoST), which is appropriate for obligatory public participatory processes in relation to harmonised quality assurance of water resource models covering different domains. If stakeholders are satisfied with their options, if acceptable decisions are emerging from traditional decision making processes, and if there are no controversies and differences in values and

understandings, then the obligatory forms will be sufficient. In such cases the protocol of HarmoniQuA / MoST can be followed as a guide both for the modelling construction and for information provision and consultations of stakeholders and general public. User Type: MA

References

1. DPSIR Framework:http://www.ceroi.net/reports/arendal/dpsir.htm User Type: MA
2. Brown, J.M. (2002) Stakeholder Involvement Plan – INEEL Water Integration Project. Prepared for U.S. Department of Energy Idaho Operations Office. July 2002. DOE/ID-10986. User Type: MA
3. Enserink, B. and Monnikhof, R.A.H. (2003) Information management for public participation in co-designing processes: Evaluation of a Dutch example. User Type: MA

1.2 Define Objectives

User Type: MA

Definition

Specification of the goals of the modelling study.

The objectives to be defined are those of the modelling study from several viewpoints. These objectives are not necessarily those of the model.

Activities

- Project Goals
- Questions to be Answered
- Scenarios
- Initial Budget
- Minimum Option

Project Goals

User Type: MA

Give a short (textural) description of the project goals.

Questions to be Answered

User Type: MA

Make a list of all questions that have to be answered in this model study.

Scenarios

User Type: MA

If the model is planned to be used for assessing the effects of environmental change or human intervention, the changes should to be quantified in terms of scenarios. Scenarios can be of non-structural or structural nature. Non-structural measures include changes to the model inputs alone, while structural measures includes construction of items that may require modifications to the model. Examples of scenarios include:- Extreme weather or climate change- New groundwater or river abstraction rules- New reservoir operation rules- Changes of measures to improve effectiveness of public reaction to flood warnings- Changes in pollutant inputs- New water charges or taxes on pollutant discharges- New well fields- New reservoir or flood protection schemes (including the effects of breaching)- Changes in land use or urbanisation- Changes in farming practices- Establishment of schemes for interbasin transfer- River channelisation or habitat creation/restoration- Use of settlement ponds and/or aeration to reduce pollution- New organisational approaches to water managementA scenario may also involve an element of iteration, where an appropriate management strategy can only be developed by trial and error simulations using the model. A 'scenario' is equivalent to a 'measure' or 'alternative' in Policy Analysis terminology or to 'decision variable' in Operational Research and model based Decision Support Systems. Within a set of scenarios (often called an ensemble), it may not be possible to define the likelihood of any individual scenario occurring. A list of the scenarios to be tested should be created, but at this early stage of the work, it may only be possible to define the scenarios in broad terms (e.g. numbers of scenarios, main features and probable configurations). Indeed, the modeller may be encouraged to develop innovative scenarios (solutions) to address specific problems. More detailed scenario descriptions can be developed at the end of the Model Calibration and Validation step. When assessing a range of measures, the option to 'do nothing' is commonly used as the first scenario.

Initial Budget

User Type: MA

Try to relate the questions and scenarios to the resources you will need.

Minimum Option

User Type: MA

Specify which questions and scenarios need to be addressed as a minimum.

Other task aspects

Sensitivities and Pitfalls

1. If this task is not completed in sufficient detail, it may result in misunderstanding between the client and the modeller later in the model study, and may disrupt relations between the parties. User Type: MA
2. Real-time application studies are often linked to desired forecast lead time and associated accuracy. Over ambitious requirements may lead to the pre-programmed failure of the study. User Type: MA
3. It is important to only set objectives that can be met by the modelling team. User Type: MA

1.3 Identify Data Availability

User Type: MA

Definition

Make a structured list of available data, including their type, quality, accessibility, and relevance to the current problem.

Activities

- Set-up Metadata Table
- System Data
- Process Parameters
- Initial Values and Boundary Conditions
- Time Series
- Scenario Data and Decision Variables
- Static Data for Calibration/Validation
- Dynamic Data for Calibration/Validation

Introduction to activities

1. The data to be described will generally include:- System data, defining the area and structure (framework) of the system in question(e.g. river or aquifer)- Process information, including spatial variations and typical parameter values- Input variables, including initial and boundary conditions, as point values and spatial distributions, covering static (steady state) and dynamic (time series) conditions- Observations of system states and outputs (both static and dynamic) for use in model calibration and validation- Descriptions of scenarios and decision variablesUsually data will be historical. However, in the case of real-time operation on-line data will be required. User Type: MA

Set-up Metadata Table

User Type: MA

Set up a structured list of the data necessary to build and run the model, identifying the data holder for each data type, its format, and who is responsible for its collection (water manager or modeller). The list should note whether QA on the data is needed. Finally, a quantitative estimate of the workload should be given, e.g. little, medium, large. The completed list should be included in the Terms of References, allowing the modeller to estimate the workload associated with data collection. The modeller may have more experience in collecting data from third parties, and the list and workload may thus be adjusted during the Task Agree on Model Study Plan and Budget.

Applicable methods:

- Metadata table

System Data

User Type: MA

Describe which of the relevant data may be needed and are available and at what level of detail. For this activity relevant data include:- Data that describe the system (e.g. river data, soil characteristics, geographical and geological maps, topographic data (DEM), and land cover)- Data that describe pollution loads, both from point and non-point sources- Schematisation data

Process Parameters

User Type: MA

Most processes can be characterized by typical process parameters. These should be listed and their availability assessed. Often, a model code provides values for these parameters, but some parameters are problem or system dependent. The latter must be available. Do not confuse these data with system data, which is not process related.

Initial Values and Boundary Conditions

User Type: MA

It may be necessary to define initial values and/or boundary conditions for state variables. Initial conditions are critical to the results in hydrological and ecological systems with long time scales compared to the planning period considered in the model study. Boundary conditions are important to ensure the initial conditions for model calculations are correct. A precise overview describing which initial values and boundary conditions are needed, or how the model is going to work without them has to be specified when the conceptual model is developed.

Time Series

User Type: MA

Describe which time series data may be needed and their availability. Variables that are not part of the system, but input to the system, are often also input for the model. This category includes (but is not restricted to): - Climate data- Water quantity and quality data from areas outside the system

Scenario Data and Decision Variables

User Type: MA

The data necessary to characterise human intervention, or uncertain driving forces, outlined under the Scenario activity in the previous task Define Objectives should be listed and their availability assessed. The data should enable predictions to be made of the impact of different scenarios / decision variables on system characteristics (related to model outputs).

Static Data for Calibration/Validation

User Type: MA

Describe and assess availability of the necessary static data. To compare the model outcomes with (in)directly measured properties of the system, data are needed during calibration or validation for system characteristics that do not vary in time or are treated as quasi stationary.

Dynamic Data for Calibration/Validation

User Type: MA

Describe and assess the availability of the necessary dynamic data for calibration/validation. To compare the model outcomes with (in)directly measured properties of the system, dynamic data are needed during calibration or validation. These data are often spatially distributed time series, sometimes available in a GIS context.

Other task aspects

Sensitivities and Pitfalls

1. **Need for proper Data** : Without proper data any model set-up will fail and also other steps in the modelling procedure will not be possible. User Type: MA
2. **Resources to ensure good Data Quality** : Collecting, structuring, analysing and performing quality check on data is often underestimated with regards to the required resources. If too little time is allocated to this task, it may lead to poor or erroneous data handling as well as lack of quality checks. User Type: MA
3. **Clear Responsibilities** : Without a precise agreement on who is responsible for the different data and at what time, conflicts may easily arise later in the modelling project. User Type: MO

References

1. The following institutions hold data relevant to ecological modelling:European Environment Agencywww.eea.eu.int/main_htmlCentre for Ecology and Hydrology (Data Centres)www.ceh.ac.ukUK Biological Records Centrewww.brc.ac.uk User Type: MA

1.4 Determine Requirements

User Type: MA,PU,SH

Definition

Specify quality standards required of the model, and define the project management structure and the resources required.

Activities

- Quality and Relevance
- Overall Quality
- Model Analyses
- Performance Criteria
- Stakeholder Expertise
- Resources
- Communication and Reporting
- Other Requirements
- Managing Model Study
- Stakeholder Opinion on Requirements
- Answers to Stakeholder Opinions and Final SIP
- Assess Uncertainty

Quality and Relevance

User Type: MA

If a model is to support decision making, requirements should be specified regarding the quality and relevance of its output. These requirements include:- Which model outputs are essential?- Which outputs have the highest priority?

Overall Quality

User Type: MA

It is essential that the overall requirements of the model study are clearly defined, or the model study may be useless. The requirements should be quantified in terms of output uncertainty, preferably after calibrating and validating the model – though this may be a difficult task for models that are multi-variate and dynamic in space and time. Uncertainty may be quantified as say an 'error' averaged over time and space or by some other measure of overall model quality. The criteria should be decided at this stage of the model study so that all parties can contribute to prioritising the study resources, and later evaluate the overall success of the work. However, numerical criteria of model quality do not always capture the full essence of how good or poor a model is. A visual appreciation of overall model quality and of where errors occur (e.g. at high or low flows, in extreme or average conditions, in quick or slow response rates, in winter or summer conditions, etc) can be as or even more important. Similarly, although formal calibration and validation are vital for getting the believable best out of a model, they are usually based on numerical criteria, and may also require considerable input and observational data that may not exist. Accepting greater uncertainty, a raw (uncalibrated and unvalidated) model could be used. However, some basic level of calibration and validation should still be possible, transferring parameters found in previous studies, and checking model performance against less objective measures of system behaviour. For example, in the PR and HD domains: model peak flows may be compared with field observations of channel capacities, or with trash lines and level marks at bridges and channel structures; model 'times to peak' and flood extents may be compared with information gained from onlookers or newspaper reports. In the GW domain, model water tables may be compared with reported spring lines or extremes in well levels. Linking the WQ, BI and HD domains, modelled and observed areas of sedimentation and habitat types may be compared. Such expert but less formalised model assessments may be compared with the Assess Soundness tasks described throughout the MoST flowchart. Depending on the overall model objectives, other circumstances in which a raw model might be used include: trying to develop a theoretical understanding of a problem; assessing or broadly ranking a number of strategic options; or even defining what additional data are most needed to develop and validate the model, and where they should be collected.

Model Analyses

User Type: MA

Define the model analyses that are needed and their purpose. Only an initial assessment is required, and this may be updated later, based on recommendations from the auditor and the modeller, in the decision tasks at the end of the five model steps. The need to model steady state and dynamic conditions (as individual events or continuous time series) should be considered. Different approaches may suit different domains, with processes occurring over a range of time scales, and data available at a mix of time steps (from under an hour to maybe three months or more). If dynamic effects are a concern, event models are generally more suitable where time-series data is scarce or has many gaps, where the problem relates to events (e.g. floods), or where model complexity would require excessive computer resources. Also, event models may omit processes that have little short term impact, and calibration can focus on conditions of most concern. By contrast, continuous simulation can involve running over long periods of little interest, and calibration may favour average rather than critical conditions. However, continuous models are usually better at representing the linkages between domains and processes that respond at different characteristic rates, and outputs do not depend on arbitrary choices of the initial and boundary conditions to use for specific events.The requirements should also define whether the analyses should include:- Sensitivity analysis, to enable the selection of parameters and other 'factors' to be used in calibration- Calibration, to reduce differences between model output and system observations- Validation, to check whether the model is generic or specific to the calibration data. Of these analyses, calibration has the highest priority and validation the highest value. Calibration can be a very complex procedure involving not just sensitivity analysis to select the parameters to adjust, but 'decoupled' calibration of model components (domains/processes/spatial units), a range of manual/automatic optimisation methods, and various performance criteria. Relevant guidance can be found under the task Specify or Update Calibration and Validation Targets and Criteria in step 3 (Model Set-up), and under the first five tasks in step 4 (Calibration and Validation). Validation is of a more generic nature and increases the credibility of the model. The system response data is partitioned, often about a selected date, with the earlier events or time-series used for calibration and the later events or time-series used for validation. Results can be affected by changes to the system (or inputs) during the data record, but also the data could be partitioned in a way that tests the model response to such changes. Alternatively, if data are available at several locations, some locations could be excluded from calibration, but used to validate the model's spatial structure. Guidance on validation methods can be found under the task Specify or Update Calibration and Validation Targets and Criteria in step 3 (Model Set-up), and under the tasks Validation in step 4 (Calibration and Validation).It should also be recognised that scenario analysis may involve making changes to the validated model. Such changes should properly be validated by post project appraisal.

Performance Criteria

User Type: MA

Performance criteria used to assess model quality may include subjective measures (based on past experience and an appreciation of model performance and parameter values), but they should also include numerical scores of how well the model performance matches observed system behaviour. Such 'goodness of fit' criteria (including the mean error and mean squared error between modelled and observed time series of system outputs) can become 'objective functions' to optimise in model calibration. Many numerical criteria could be used, each prioritising the goodness of fit to different aspects of system behaviour (water levels, high flows, low flows, annual peaks, forecast accuracy at different lead times, pollutant flushes, annual loads, biodiversity scores, etc). Not all these criteria are equally useful or can be easily interpreted. The choice of performance criteria is a subjective decision, particularly in multi-objective studies, where the balance of priorities between achieving the various objectives must also be considered. To improve communication between the water manager and the modeller, the numerical criteria to be used and their method of calculation should be specified. Similarly, a precise definition of the test sample should also be given by the client. This will prevent the modeller only choosing those events where the model performs adequately. However, model performance should not be assessed by numerical criteria alone, and guidance on the role of qualitative criteria is given in the tasks All Calibration Stages Completed and Assess Soundness for calibration and validation.If the water manager wants model performance to be assessed comparatively to a benchmark model (i.e. a reference model) then this should be specified. This may be a simple model (just derived from data) or more sophisticated. The objective is to provide a reference that should be exceeded to ensure good model credibility. For example, the mean observation may be used as a reference, comparing the mean square error between observed and modelled values with the mean square difference between observed values and their mean (see Nash-Sutcliffe). For real-time forecasting, a more useful reference is the current value (i.e. no change during the forecast lead time), comparing the mean square forecast error with the mean square difference between observed values separated by the forecast lead time (see Persistence Criterion). The requirements defined here may be reviewed during the project. Additional guidance is given under task Specify or Update Calibration and Validation Targets and Criteria in step 3 (Model Set-up).

Stakeholder Expertise

User Type: MA

Assess and describe the requirements of stakeholders in terms of domain expertise.To address a specific problem with a model, stakeholders must have expertise in appropriate domains. If the required expertise cannot be provided by the project participants, then there must be a plan of how to acquire it.

Resources

User Type: MA

An estimate must be made of the resources required to complete the project. There may be external forces or other reasons which restrict the amount of time/manpower available and these must be taken into account during the planning of the project. There must be a clear relationship between the size of the project (time, manpower, computing equipment and budget) and its level of ambition. An indication of the global time required may be expressed as follows (the percentages below vary from case to case):- Step 1: Model Study Plan - 10 %- Step 2: Data and Conceptualisation - 20 %- Step 3: Model Set-up - 20 %- Step 4: Calibration and Validation - 30 %- Step 5: Simulation and Evaluation - 20 %Feedback loops mean that some steps and tasks are performed more than once. The time expenditure given here refers to the total time to be spent. Occasionally, there may be a ready-made model which can be deployed directly and, in this case, Steps 1, 2 and 3 will take far less time.

Communication and Reporting

User Type: MA

The requirements for Communication and Reporting should be clearly defined.In the HarmoniQuA flowchart, each step ends with a decision task: - Step 1: Agree on Model Study Plan and Budget- Step 2: Review Conceptualisation and Model Set-up Plan- Step 3: Review Model Set-up and Calibration and Validation Plan- Step 4: Review Calibration and Validation and Simulation Plan- Step 5: Review of SimulationThese decision tasks facilitate regular discussions between the water manager and modeller, based on the modeller's report on the work done in that step and draft updates to the Model Study Plan for the next step. This should diminish the risk of different perceptions on the frequency and form of communication and reporting. However, the water manager and modeller should be explicit on other communication and reporting requirements by specifying their focus, direction and frequency.The level of detail required in communication and reporting will depend on the job complexity, and for relatively straight-forward studies, reporting and review tasks could be handled by less formal progress reports and project management meetings.

Other Requirements

User Type: MA

Discuss and list the additional requirements that should be included in the Terms of Reference. These may include:- Use of the results from other models and the requirements which must be set for that purpose- Supply of results from current modelling project for use by other models- Scientific reporting- The hypotheses on which the model is based- The quality of the field data- Formulation of responsibilities for the final completion of the model study- How to deal with results originating from two or more different approaches (with various models and/or model programmes)- Transfer of model results and/or model implementation to the client- Transfer of uncertainty information to the client- Translating model results into policy advice- Provision of digital files of model results- Archiving of results and model- Service in maintenance/warranty period- Possible post audit (post project appraisal) as a follow up to the present modelling study

Managing Model Study

User Type: MA

Decide and document whether model study will be undertaken in-house or put out for tender. If put out for tender then it should be considered (decided under the task Proposal and Tendering) whether there will be a call for a single tender or multiple tenders and whether tenders will involve pre-qualifications or be open. In cases of domains and/or modelling projects that are relatively specialised, single or limited tenders are often advantageous.

Stakeholder Opinion on Requirements

User Type: PU,SH

Document stakeholder opinions on requirements.HarmoniQuA addresses the minimum requirements, of the WFD, for stakeholder and general public participation (i.e. information provision and consultation) by allowing them to provide input at the start of the project (Model Study Plan) and to comment on work as it progresses during review tasks. When requirements are determined, stakeholders and the general public shall be allowed to provide comments and opinions on the Model Study Plan which includes the Stakeholder Involvement Plan (SIP) developed by the manager and discussed with the modelling team.According to the WFD it is the responsibility of managers to provide information to stakeholders and the general public about management timetables, issues and the participants, which are considered to be the foundation for all further participation activities. Furthermore, the WFD states, that the manager is responsible for proper consultation which should include encouraging written and oral responses. Stakeholders and the general public should provide feedback on needs for adjustment of preferred interaction and communication tools (according to SIP) that are to be used for the subsequent step until next stakeholder feedback in task 2.12 Review Data and Conceptualisation and Model Set-up Plan (se method Interaction and communication ABC).Comments and opinions should be structured according to the SIP (see Activity Prepare Stakeholder Involvement Plan - SIP).

Applicable methods:

- Interaction and Communication ABC

Answers to Stakeholder Opinions and Final SIP

User Type: MA

Evaluate and respond to stakeholder opinions on requirements. Responses should be structured according to the SIP (see activity Stakeholder Involvement Plan). The final and adjusted SIP should be included in the Terms of Reference, discussed with the modeller and subsequently included in the Model Study Plan.During this process where adjustments to the SIP are carried out, Interaction and Communication Tools and actor regrouping may be necessary (see methods Interaction and Communication ABC and Actor grouping).

Applicable methods:

- Interaction and Communication ABC
- Actors grouping

Assess Uncertainty

User Type: MA,PU,SH

Document the requirements for assessing uncertainty. The water manager should assess the uncertainty involved in the modelling study in consultation with the stakeholders/public. This activity will also require some modelling expertise. If the water manager does not have sufficient modelling expertise in his own organisation he will need to get support from external experts for this activity.Uncertainty should be assessed in a broad context and it must not be limited to statistical uncertainty that is commonly addressed in comprehensive modelling studies. Thus the uncertainty should also include types of uncertainty that cannot be characterised by probabilities, but may be characterised in terms of scenarios or in qualitative terms. Furthermore, areas and processes where knowledge is known to be incomplete should be included.The purpose of this activity at this early stage of the modelling study is to draw attention to uncertainty to ensure that the modelling study is designed so that it addresses the issues where there is expected to be most uncertainty and where it is possible to reduce the uncertainty.The activity should use the Uncertainty Matrix or a similar qualitative method as a dialogue platform between the various parties.

Applicable methods:

- Uncertainty Matrix

Other task aspects

Sensitivities and Pitfalls

1. **Importance of clearly defined Requirements** : This is a difficult part of the model study. Many disputes between the modeller and the client are caused by a lack of clear appointments on many of the activities of this task. For jobs of a more basic nature standard formulation can be used, but even then one should be explicit. User Type: MA,PU,SH
2. **Performance Criteria** : Establishment of performance criteria specifying the required accuracy of the model simulations is a very difficult task. The level of acceptable risk or uncertainty in a decision situation cannot be generalised. It will vary from country to country and from river basin to river basin according to the site specific socio-economic conditions. Or in other words in situations where much is at stake either economically and/or politically more accurate modelling simulations may be required. Usually, higher performance requirements will require better data and more thorough modelling studies and will therefore often be more costly. The trade-off between accuracy requirements and costs involved need to be made by the water manager after consultation with other relevant parties. User Type: MA,PU,SH
3. **Public Participation** : Public participation can be weakened by a lack of resources (time, money, staff), a lack of rules of participation, a lack of in-depth involvement of authorities, a lack of hands-on in use of MoST for the stakeholders and general public and a lack of professional supervision of the process User Type: MA,PU,SH

References

1. A guidance on methods and approaches in uncertainty assessments can be found on the Harmoni-CA web site (http://www.harmoni-ca.info).The sets of criteria proposed in the River Basin Management Toolbox (http://www.rbm-toolbox.net/) may be useful to orientate the model assessment framework. User Type: MA
2. References about criteria:Nash, J. E. and Sutcliffe, J. V. (1970). River flow forecasting through conceptual models. Part I - A discussion of principles. Journal of Hydrology, 27(3), 282-290.Kitanidis, P. K. and Bras, R. L. (1980). Real-time forecasting with a conceptual hydrologic model. 2. Application and results. Water Resources Research, 16(6), 1034-1044. User Type: MA
3. ISO 9001 "Quality management systems"ISO 9004 "Quality management systems - guidelines for performance improvements" User Type: MA
4. European Communities (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No 11, Planning Process. User Type: MA,PU,SH

1.5 Prepare Terms of Reference

User Type: MA

Definition

Terms of Reference are the specifications for the modelling study.

Terms of Reference are written to describe the requirements of the study. These will include: scope of work, accuracy, time schedule, role of modelling within overall study plan, allocated resources and the responsibilities of the modeller (consultant). The Terms of Reference form the basis of the modeller's proposal or tender to carry out the modelling study and his/her subsequent work.

Activities

- Prepare Terms of Reference
- Establish Model Study Plan

Introduction to activities

1. Preparing the Terms of Reference involves collating the requirements of the model study, specified in the task Determine requirements, into a single document as described below.The Terms of Reference should specify that the technical part of the proposal should be written so that it fits into the content of a Model Study Plan (as given below). The table of contents of the Project Report, prepared during the modelling process, should be very similar to the table of contents for the Model Study Plan. User Type: MA

Prepare Terms of Reference

User Type: MA

Write Terms of Reference. They are likely to include the following:1. Background (problem description)2. Data availability3. Modelling study objectives4. Modelling study outputs5. Scope of work (methodology and activities)6. Calibration, Validation, and Model performance7. Possible Post Audit8. Time schedule9. Resources allocated10. Reporting requirements, schedules for progress and final reports10. Management procedure, including specification of reviews 11. Required table of contents for Model Study Plan

Establish Model Study Plan

User Type: MA

A Model Study Plan outlining the content of the modelling project should be established prior to starting modelling. A table of contents would typically include:0. Executive Summary1. Introduction (problem description, data availability, objectives, specifications, stakeholder involvement plan)2. Technical approach (overall methodology for performing the job)3. Conceptualisation4. Model Set-up5. Model calibration6. Model validation7. Model simulation (including uncertainties)8. Project completion (transfer of results to manager, archiving, training, service in maintenance/ warranty period, etc.)9. Conclusions and recommendations10. ReferencesAppendicesThe table of contents is in accordance with the HarmoniQuA procedures so that the step Model Study Plan is reported in Chapter 1+2; the step Data and Conceptualisation in Chapter 3; the step Model Set-up in Chapter 4; the step Calibration and Validation in Chapters 5+6 and the step Simulation and Evaluation in Chapter 7. This structure makes it possible to finalise the chapters one or two at a time in connection with the progress of the modelling job. Depending on the content of the Terms of Reference some of the above chapters (and some of the steps) may not be required for some modelling jobs.

Other task aspects

Sensitivities and Pitfalls

1. **Room for Creativity** : If the Terms of Reference is too detailed on how to do things it may leave too little room for creativity and too little responsibility with the modeller in the subsequent contract and throughout the modelling job. User Type: MA
2. **Detailed TOR** : If the requirements in the Terms of Reference are not sufficiently detailed and precise there is a risk that the water manager and the modeller adopt different interpretations on the requirements to outputs and required work. If this occurs it may be not possible to prepare a good contract that ensures an operational execution of the modelling job. It is important that the Terms of Reference describes what has to be done, when should it be done and to which accuracy level. User Type: MA

1.6 Proposal and Tendering

User Type: AU,MA,MO

Definition

Tendering is the process of selecting a consultant for a modelling job on the basis of technical and financial proposal(s)

A consultant may be selected either directly or through a competition among several consultants who are requested to prepare proposals for the study. The task involves two important elements, namely that the modeller prepares technical and financial proposals and these are evaluated by the manager.

Activities

- Select Tendering Procedure
- Initiate Tendering Process
- Prepare Proposal
- Evaluate and Select Proposal

Introduction to activities

1. The activities in the task should be carried out by three parties:- Water manager (steering of tendering and negotiation process)- Modeller (preparation of proposal and participation in contract negotiations)- Auditor (evaluation of proposals) User Type: AU,MA,MO

Select Tendering Procedure

User Type: MA

Describe which tendering procedure will be used. The selection of tendering procedures is confined by EU and national legislation.

Applicable methods:

- Invited Tender without Pre-qualification
- Invited Tender with Pre-qualification
- Sole Source
- Open Tender

Initiate Tendering Process

User Type: MA

Initiate and record tendering procedure:- In case of 'direct negotiations': invite selected consultant to prepare a proposal in accordance with the given Terms of Reference.- In case of 'Invited tender without prequalification': invite selected consultant to prepare a proposal in accordance with the given Terms of Reference.- In case of 'Invited tender with prequalifications': invite selected consultant to prepare prequalification material and on this background select suitable consultants and invite them to prepare proposals in accordance with the given Terms of Reference. - In case of 'open tender': announce publicly the call for proposals and provide Terms of Reference to interested consultants.

Applicable methods:

- Invited Tender without Pre-qualification
- Invited Tender with Pre-qualification
- Sole Source
- Open Tender

Prepare Proposal

User Type: MO

Prepare a two part proposal:- A technical proposal addressing all the points described in the Terms of Reference. The Technical Proposal generally has to be in accordance with the HarmoniQuA guidelines and in particular the content of the Model Study Plan must be explicitly described- A financial proposal providing the financial details and prepared in accordance with the contractual conditions set up by the manager

Evaluate and Select Proposal

User Type: AU,MA

Analyse the Technical Proposal(s) and identify to what extent they technically comply with the Terms of Reference.Select the best proposal from an overall evaluation of the technical and financial proposals. A proposal evaluation support tool is available as an attached file to the KB.

Applicable methods:

- Proposal Evaluation

Other task aspects

Sensitivities and Pitfalls

1. **Selection of Consultant** : Selection of the right consultant is important to ensure a productive and successful outcome of the modelling study. Considerable time, effort and expense can be wasted in managing projects if consultants underbid for work and do not appreciate the very high time input which may be involved in performing a good job. The cheapest offer is not always the best one - the

weighting between price and quality is non-trivial. User Type: AU,MA,MO

2. **Open tenders** : Open tenders may generate a lot of proposals, but consultants often hesitate to put a lot of resources into writing of the proposal if the chance of success is expected to be very small, which is often the case in open tenders. Hence, open tenders may not result in as good and well prepared proposals as some of the other methods. User Type: AU,MA,MO
3. **Selection of Consultant** : Selection of the right consultant for the development of real time applications is often based on the balance of consultant's capabilities to develop or select the right model and also to ensure its successful real time application. Teams or consortia having references in both fields are the best candidates for a flood forecasting project. User Type: AU,MA,MO

References

1. Sites with description of standard procedures and conditions (e.g. EU tendering procedures, EC directives etc.) (see e.g. http://www.europa.eu.int/) User Type: AU,MA,MO

1.7 Agree on Model Study Plan and Budget

User Type: MA,MO

Definition

The water manager and the modeller make an agreement on the technical and financial conditions of the modelling study.

This is essentially the contract negotiation phase where the client (manager) and the consultant (modeller) negotiate on the technical specifications and the financial conditions of the modelling study.

Activities

- Technical Content and Budget
- Prepare Model Study Plan
- Quality Assurance Plan

Introduction to activities

1. The water manager and the modeller negotiate on the basis of (a) the Terms of Reference prepared by the water manager, and (b) the proposal subsequently prepared by the modeller. If they can reconcile the proposal and associated Model Study Plan with the Terms of Reference then a formal agreement can be reached. If agreement is not possible, the process loops back to reconsider the task Define Objectives. User Type: MA,MO

Technical Content and Budget

User Type: MA,MO

Conduct and document negotiations that are chaired by the manager with the aim of reaching agreements on:- Technical contents of work- Budget- Payment schedule

Prepare Model Study Plan

User Type: MA,MO

On the basis of the agreed technical content of the work, the first version of the Model Study Plan shall be prepared with the table of content as described under in the Terms of Reference. As the technical proposal from the modeller has been prepared with the same table of content this proposal can, with the modifications that may have been agreed upon during the negotiations, form the basis for Model Study Plan.

Quality Assurance Plan

User Type: MA,MO

On the basis of the agreed Model Study Plan the dedications and tasks in MoST should be adapted to the present model study. This implies:- To agree on which domains are included- To agree on which tasks (and possibly activities) are included and which may be skipped- To agree on which types of external reviews should be carried out at the four review tasks in Steps 2, 3, 4 and 5.- To agree on which persons will be involved in the project and their respective responsibilities and to implement this in MoST in terms of user authorisations, etc.To support the selection of which tasks to be included a number of Job Type Templates is available within MoST. These examples of possible tasks for different types of modelling studies are intended as inspirations only and will usually require adaptation to fit to the modelling study at hand. Finally, in this task it should be decided if, as an addition to the present KB/MoST, other modelling guidelines should be used. This could for instance be more specific national or sectoral guidelines.

Other task aspects

Sensitivities and Pitfalls

1. **Model Code** : At this stage, the water manager and the modeller may already agree on the model code or software that will be used during the study. Else, this will be determined later in the following Steps. User Type: MA,MO
2. **Model Journal** : The model journal has no direct influence on the modelling process. However, when passing on modelling tasks and when re-using the model and data files (after some time), the lack of full information can lead to incorrect interpretation. For example, because it is no longer simple to deduce which output is related to which input. The completion of a good model journal is a rarity. Two common pitfalls are:- the model journal is incomplete,- the model journal is incomprehensible, not only for third parties but often also for the author himself.Both pitfalls have a lot to do with time and motivation. Little can be done about the latter, keeping a model journal is simply no fun. However, the time factor can be influenced, by planning sufficient time for this aspect beforehand, for example. It is also a question of investment. For the short term, keeping a model journal costs time, but this time will be earned back amply in the longer term, when looking to determine exactly what work has already been carried out. User Type: MO
3. **Job Type Template** : When selecting a job type template that does not include all tasks some of the feedback loops may end in the "wrong" taks. This should be taken care of manually and may require consulting some of the guidance for non-included task descriptions User Type: MA,MO

Step 2: Data and Conceptualisation

This step involves the Modeller bringing together all the relevant knowledge about the study basin, and using this to develop an overview of the processes acting, their interactions, and how the system should be modelled in sufficient detail to meet the aims defined in the Model Study Plan agreed in Step 1.Collating and reviewing the extent and quality of available data from the basin should go hand-in hand with assessing the processes that govern the basin response and how they can be represented in an appropriate manner. Consideration must be given to the spatial and temporal detail required of a model, to the system dynamics, and to how the model parameters can be determined from the available data (by prior evaluation using text-book defaults, by spatial aggregation, or by calibration against observed data). Model details should be clearly itemised, listing assumptions, strengths and limitations. The need to model certain processes in alternative ways or to differing levels of detail should be assessed. The availability of existing computer codes that can address the model requirements should also be addressed.The results of the data collation and conceptual model analysis are reported to the Water Manager for review and reassessment before proceeding to the Model Set-up step.

2.1 Describe System and Data Availability

User Type: MO

Definition

Identify the processes to be represented, and the data needed, to set up and validate a model of sufficient complexity to meet the objectives defined in the Model Study Plan.

Activities

- Processes to be simulated
- Data to set-up and run model
- Data to analyse model output
- Data availability

Processes to be simulated

User Type: MO

Prepare an inventory of the processes that should be represented in order to fulfil the modelling objectives. The inventory is a preliminary one enabling an assessment of data requirements and availability. A more precise and final description of model processes follows in the task Model Structure and Processes.

Data to set-up and run model

User Type: MO

Prepare an inventory of data needed to define the model structure, input data (initial values and input time series), parameters (processes), and management scenarios. Data requirements for a groundwater model may include some or all of the following:- Physical System-- Geologic data (borehole data and geophysical data)-- Geochemical data (e.g. depth to redox front)-- Topographic maps showing surface water bodies and divides-- Soil maps-- Maps showing the distribution of subsurface drains-- Cross-sections of streams-- Land use maps-- Location of point sources for pollutions / threats- Hydrogeological Framework-- Water table and piezometric surface maps for all aquifers-- Hydrographs of groundwater heads and surface water levels and discharge rates-- Maps showing the hydraulic conductivity and/or transmissivity distributions, if available-- Maps showing the storage properties of aquifers and confining units, if available-- Spatial and temporal distribution of rates of evapotranspiration, precipitation, groundwater recharge-- Spatial and temporal distribution of groundwater abstraction rates- Calibration and Validation Data-- Maps showing the location of monitoring wells and associated groundwater levels-- Time-series of groundwater levels for dynamic simulations-- Streamflow measurements-- Solute concentration measurements- Management scenarios-- Maps showing the location and stresses of proposed management scenarios.

Data to analyse model output

User Type: MO

Prepare an inventory of additional data needed (measurements or system observations) for model calibration and validation. Data requirements include:- Maps showing the location of monitoring wells and associated groundwater levels - Hydrographs of groundwater levels- Maps showing the distribution of discharge to streams and springs- Maps and cross-sections showing groundwater age distributions- Maps and cross-sections showing solute concentrations

Data availability

User Type: MO

This activity will relate the specific data needs identified in the present task with the Metadata Table prepared in the Task Identify Data Availability, preparing:- a list of the required data that are available for the present model study- a list of the required data that are not available.It will also typically include:- A literature review conducted with the objective of identifying and quantifying the important aspects of the system, data reliability and the processes that control or impact the system.- A compilation of reports and data from previous modelling studies.- A compilation of other available reports and datasets and identification of relevant material.

Other task aspects

Sensitivities and Pitfalls

1. **Data Inventory and Model Processes** : The inventory of data needed to construct, run or analyse a model cannot be made independently from an analysis of the processes to be represented in the model. These aspects are closely linked and should be considered together. User Type: MO
2. **Species Data** : The distribution, abundance or biomass of one species may be dependent on an infinite list of abiotic and biotic factors. For instance they may be dependent on the distribution of many other species, the concentrations of several trace elements or the presence or absence of millions of taxa of virus, fungi, predators and bacteria. Expert knowledge may be needed to produce a refined list of essential data. User Type: MO

References

1. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO
2. Jay R. Lund, et al. : Economic-engineering analysis of Californian water management, in: Integrated Water Resources Management (Proceedings of a symposium held at Davis, California, April 2000, IHS Publ. No. 272, 2001. http://cee.engr.ucdavis.edu/faculty/lund/CALVIN.Modelling and decision

Support Framework for Catchment Flood Management MDSF, http://www.mdsf.co.uk.X. Cai, D.C. McKinney and L.S. Lasdon: Integrated Hydrologic-Agronomic Model for River Basin Management. Journal of Water Resources Planning and Management, January/February 2003, 4-17.Hynd Bouhia: Water in the Macro Economy. Integrating economics and engineering into an analytical model, Ashgate, Burlington USA, Singapore, Sydney.R.A. Jensen, J.Krejcik et al.: River Basin Modelling in the Czech Republic to Optimise Interventions Necessary to Meet the EU Environmental Standards. Paper presented at the International Conference of Basin Organisations, Madrid, Nov. 4-6, 2002: Ministerio de Ambiente, Dirreccion General de Obras Hidraicasy Calidad de Aguas, Madrid, Spain.Merret S. (1997): Introduction to the Economics of Water Resources. London.A.S. Goodman (1984): Principles of Water Resources Planning. London, Sydney, Toronto. User Type: MO

3. National Weather Service (NWS) Modernization Committee, Commission on Engineering and Technical Systems, National Research Council (1996): Toward a new national weather service, Assessment of hydrologic and hydrometeorological operations and services, National Academy Press, Washington, D.C. 1996 (http://books.nap.edu/html/hydro/) User Type: MO

2.2 Collect and Process Raw Data

User Type: MO

Definition

Collection, pre-processing and evaluation of raw data.

Raw data comprise framework and stress data. The framework data describe the physical system, and parameters that do not change with time. The stress data describe the dynamic stresses in the system (initial conditions, time-varying data and the translation of management strategies into modelling scenarios). The raw data are organised, database software and format are selected and data are entered into a database. Finally, qualitative and quantitative checks of the pre-processed raw data are performed. This can be an ongoing task that continues in parallel with subsequent tasks to increase the available data for model testing and scenario analysis. Similarly, new field data collection and monitoring networks may also be set up.

Activities

- Collect raw data
- Pre-process raw data
- Evaluate pre-processed data

Introduction to activities

1. The activities in this task can be ongoing, continuing in parallel with subsequent tasks to increase the available data for model runs and analysis. User Type: MO

Collect raw data

User Type: MO

Collect data to be used in Conceptualisation, Model Set-up, and Calibration and Validation. For groundwater flow models this includes information describing the regional geology, climate, groundwater levels, physical descriptions of stream system and flow measurements, land use, topography, soil types and groundwater extraction. If solute transport is considered, available data on observed concentration is also collected. For reactive transport geochemical data is also collected. The latter data type is often scarce and may have to be supplemented by a literature review.

Pre-process raw data

User Type: MO

- Define the structure or format of the database- Select an appropriate database (software) for use in storage, manipulation and output of data- Enter the raw data into database. In choosing a database, consideration should be given to storing model outputs and possibly model structure information within the same structure. This would facilitate any comparisons of system observations (inputs and response) with one or more modelled responses (suitably linked with corresponding model version information). The database could also be used to store scenario outputs as required in Task Simulations.

Evaluate pre-processed data

User Type: MO

Based on the lists created in the previous Task under Activity Data availability, prepare an inventory of the data being collected, and for each data source and/or monitoring site:- Record the properties and characteristics of the pre-processed raw data.- Record the source of the data, how it was measured and by whom.- Assess and record how accurately the data were measured, including their representativeness. The accuracy of hydraulic head measurements is dependent upon the accuracy of the measurement technique (hand measurement or transducer), the accuracy at which the well location was determined and the temporal and spatial scale for which is should be representative. The accuracy of water quality data is dependent upon sampling and analysis method.- Determine and record the applicability of data collected from other environments/water bodies by assessing if the geographic range, geology or season of data collection is comparable to the catchment to be modelled. - For time series data, identify any sub periods (e.g. events) that are to be treated separately- Apply appropriate methods (see Visualisation and Tabulation, etc) to check the data sets (and any sub periods) for their consistency - especially for data sets obtained from different sources. - Record the outcome of these tests, identifying any data should be rejected (and why), and also identifying data that has passed the evaluation tests and is deemed acceptable for the modelling study. This data is referred to as 'Qualified Data'. Note that systematic and small errors in the measurement of hydraulic head and flows may go unnoticed. However, anomalous observations may be indicative of measurement error and unknown external factors such as the influence of a pumping well on groundwater levels or the impacted of storm water or municipal discharge and irrigation diversion/pumping from streams on stream flows.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Contouring
- Correlation and Regression
- Aggregation
- Surface Fitting
- Scatter plots
- Site visits and Photographs
- Pumping tests and slug tests

- Spatial Interpolation and Integration
- Rating curves
- Double Mass Curves
- Infilling (temporal)
- Zonation

Other task aspects

Sensitivities and Pitfalls

1. **Use Existing Data** : Identifying and obtaining data collected by others takes time and effort, as all relevant materials may not be in the public record. However, this activity may substantially reduce the length and cost of the project. User Type: MO
2. **New Data** : If it is necessary to collect new data, these efforts should be guided by specific project needs. User Type: MO
3. **Flexibility of Database** : At this stage, the format of data input to software used in constructing and analysing the model may not be known. Therefore, the database selected for the raw data should be flexible enough to allow for easy export of data to other software used in the project. User Type: MO
4. **Data Accuracy** : It may not be possible to determine accuracy of data collected by others. User Type: MO

2.3 Sufficient Data?

User Type: MO

Definition

Determine if there is sufficient qualified data to fulfil the project objectives as defined in the Model Study Plan. Qualified data refers to data that has been collected, evaluated and deemed applicable for use in the model study.

Activities

- Data to set-up and run model
- Data to analyse model output

Data to set-up and run model

User Type: MO

Determine whether the quality and quantity of the qualified data is sufficient to set-up and run the model - based upon the inventory of data needs defined in the task Describe System and Data Availability. For real time applications corresponding models should be defined for different cases of data availability.For models with spatially distributed parameters deduced from field measurements, sufficient spatial information should be available for their calibration.

Data to analyse model output

User Type: MO

Determine if the quality and quantity of the qualified data is sufficient for model calibration and validation based upon the inventory of data needs defined in task Describe System and Data Availability. If it is determined that there is not enough data, then outline the data types that need to be collected.For dynamic modelling, long enough time-series should be available to calibrate and validate the model on non-overlapping periods (typically several years) including a wide enough range of climatic/water quality conditions.Activities to collect and process additional data are included in the first task of each following step.

Other task aspects

Sensitivities and Pitfalls

1. **Lack of Data - Lack of Process Understanding** : If there is a lack of sufficient qualified data, it is likely that there is also a lack of understanding of important processes. Most likely it will not be possible to develop a model of high complexity at this stage. Either additional data needs to be collected or the

complexity of the model as defined in the Model Study Plan needs to be revised User Type: MO

2. Agree on Data Format : If data are available in an inappropriate format (e.g. should be digitised), an agreement between the modeller and the manager should be found on that issue. User Type: MO
3. Seasonal Dynamics : Water quality processes often depend strongly on seasonal forcings, such as temperature, light and riverflow. Hence, it is very important that data is available for a variety of seasons and weather conditions. User Type: MO
4. Sufficient Data? : Data insufficiencies may not be recognisable at this stage of the modelling process, but may become more apparent during model calibration and validation. User Type: MO
5. Aggregated Data Sufficient? : It should be clarified to which extent using average data (temporal, spatial) is appropriate. This aspect is important for linking socio-economic data (e.g. water use) with hydrologic model components (e.g. groundwater availability) as infrastructure for transport and (temporary) storage of water typically has substantial cost implications. User Type: MO

2.4 Model Structure and Processes

User Type: MO

Definition

Delineate the physical extent, dimensionality, internal framework, boundaries and processes of the model domain, and describe how they will be represented mathematically.

The model structure defines how the physical environment is represented in the model. This includes the extent of the model domain, dimensionality (1-, 2- or 3-D), internal framework, dynamics (steady-state or transient) and location and type of boundary conditions (interaction of the model study area with the surrounding environment). The dominant processes / statistical relationships are identified and represented mathematically, including those needed to model the required scenarios. The level of model complexity determines to what degree processes are simplified in the model. This task is essential when a physically-based or conceptual modelling approach is adopted. But it may be less important for other approaches, e.g. empirical or "black-box" approaches, or if an existing model has been already pre-selected.

Activities

- Analyse system relations
- Physical extent
- Water budget
- Geological framework
- Model dimensions
- System dynamics
- Model boundaries
- Recharge
- Surface water
- Fractures/preferential flow
- Density effects
- Reactive transport

Analyse system relations

User Type: MO

Make a thorough analysis of available data with the aim of obtaining a good understanding of system behaviour. This understanding will be essential for defining the conceptual model.

Physical extent

User Type: MO

Determine the area of the catchment to be modelled. The area may e.g. be shown on maps or in a GIS. In some cases, topographic and groundwater divides may not coincide. This may influence the modelling and should be taken into account.

Water budget

User Type: MO

Assess the water budget. The water budget is a description of the inflows and outflows across external and internal model boundaries and is prepared from field estimates. Inflows may include groundwater recharge from precipitation, overland flow, recharge from surface water bodies or subsurface recharge across external model boundaries. Outflows may include pumping, baseflow to surface water bodies, springflow, evapotranspiration and subsurface discharge across external model boundaries. Many terms in the water budget can not be measured in the nature. The water budget for the conceptual model must therefore be evaluated by setting up a balance for all known quantities, and evaluate whether the discrepancy between inflows and outflows can be explained by the not measurable terms, e.g., flow across external boundaries.

Geological framework

User Type: MO

Describe geological framework. Geologic information (geologic maps, cross-sections, well logs and borehole data) is combined with information on the hydrogeological properties to define hydrostratigraphic units. Hydrostratigraphic units are comprised of geologic units with similar hydrogeological properties. Several geologic units may comprise a single hydrostratigraphic unit or a geologic formation may be subdivided into aquifers and aquitards. Geologic units represent coherent zones which may help with parameterisation in the later task Model Parameters.

Model dimensions

User Type: MO

The dimensions of the model are determined based upon the geological framework and the level of detail required to meet the objectives defined in the Model Study Plan. Models may be 2-D,Quasi 3-D or Fully 3-D.

System dynamics

User Type: MO

Determine whether the system should be represented by steady-state or transient conditions and associated temporal resolution that may vary from less than one hour to years. Examine hydrographs and flow data from drains, streams (baseflow component) and springs and maps of groundwater levels and hydrographs to determine the magnitude of the dynamics of the flow system. This data should be compared with precipitation and evapotranspiration data in order to determine the response of the system to recharge and discharge. For steady state models a period must be selected were the steady state assumption for the system is reasonable.

Model boundaries

User Type: MO

Define the model boundaries.Boundaries describe how the model study area interacts with the surrounding environment and are described by specified head/concentration, specified flux, head-dependent flux conditions or fixed head/concentration gradients. Boundaries present along the edges of the model domain are referred to as model boundaries, whereas boundaries present within the model domain are referred to as internal boundaries.

Recharge

User Type: MO

Determine how recharge is represented in the model. Should processes in the root zone and unsaturated zone be represented explicitly in the model? If so, should flow in the unsaturated be described based upon soil moisture/tension relations (Richards' equation or equivalent), gravitational flow or a simple black box model? Is it necessary to describe preferential flow in the unsaturated zone or will equivalent effective parameters suffice? Should hydraulic parameters representing the unsaturated zone be distributed or lumped? Can recharge be estimated using available precipitation and evapotranspiration data and used as model input? For many reactive solutes, the upper soil is the most reactive area (e.g. sorption and degradation) and an explicit representation of the unsaturated zone may be required for the transport simulations.

Surface water

User Type: MO

Determine how surface water systems (streams, lakes, wetlands) will be represented in the model. Is it necessary to describe flow processes within the surface water system or can they be described by an external/internal boundary condition such as constant head or head-dependent?

Fractures/preferential flow

User Type: MO

Determine how fracture systems or lenses that lead to preferential flow paths will be represented in the model. Can an equivalent porous medium (EPM) approach be used to represent fractures or is it necessary to explicitly represent fractures using a double porosity or discrete fracture model approach? Is it necessary to explicitly represent lenses of high of low permeability or can average hydraulic conductivity values be used? While some simplifications may be adequate for bulk quantities, transport often dictates a much more detailed representation.

Density effects

User Type: MO

Determine whether the effects of density need to be accounted for in systems with high salinity or temperature. For some systems, it may be sufficient to describe density effects using an equivalent freshwater head approach.

Reactive transport

User Type: MO

Determine how the reactive processes should be described, e.g., first-order degradation vs. Monod like expressions coupled to microbial growth, or instantaneous equilibrium sorption vs. kinetic sorption, linear vs. non-linear sorption, etc. Also determine if the geochemistry in the model domain needs to be represented explicitly, to account for spatial variations.

Other task aspects

Sensitivities and Pitfalls

1. **Areas of Model and Data** : For some systems, the data considered during this task should encompass observations from an area or region considerably greater than the model area User Type: MO
2. **Model Structure Error** : Improper representation of the internal framework may lead to unrealistic parameter values through calibration User Type: MO
3. **Boundary Conditions** : The location and type of boundary conditions may greatly influence the model solution, with some types of boundary conditions having a stronger impact on the model results than others. In an attempt to minimise the influence from the boundaries, the model area should always be considerably larger than the focus area. Dominance by wrong model boundaries may be compensated for in the model calibration and thus lead to highly erroneous parameter estimates. Some boundaries may be temporal variable, the importance of a large model area becomes therefore even more important if the model is to be used for predictive simulations, due to the uncertainty in future boundary conditions. User Type: MO
4. **Adaptability of Ecosystems** : Ensure that the model reflects the real properties of the ecosystem being studied. Dynamic adaptability of ecosystems makes them very different from other physical systems. User Type: MO
5. **Relevance and Dynamics of Processes** : Relevant processes must be adequately described in order to improve the accuracy of model predictions. In particular, too little attention is often given to specifying process speeds. However, at this stage of the modelling process it is often difficult to fully determine the relevance of individual processes. User Type: MO

6. **Black Box Model** : If an empirical or "black box" modelling approach is adopted, the activities related to process identification are not necessary User Type: MO
7. **Model Complexity** : Including too many processes, a tempting approach in water quality, usually leads to many calibration parameters. The risk is that calibration becomes curve-fitting, with little relation with reality. User Type: MO
8. **Boundary Conditions** : The uncertainty of future boundary conditions may dominate the model solution and forecast error if the model area is not large enough User Type: MO
9. **Scale** : Spatial and temporal scales are particularly important for ecological models. As the response times of various organisms varies considerably it is very important to use an appropriate time scale in the model. User Type: MA
10. **Geological Model** : Knowledge on the geological setting will always be incomplete. Depending on the model objectives, the lack of knowledge on the geology will be of more or less importance to the model results. Local scale variations in the geology may be of only minor importance for large scale modelling when focus is on a quantitative estimate of the resource. On the other hand, transport simulations are often highly influenced by the lack of knowledge for even local scale heterogeneity. In the case of reactive transport the geochemistry and its spatial variation may additionally play a significant role, but is only rarely known in detail. The importance of the lack of knowledge in the model structure should therefore be evaluated in light of the model focus, and this evaluation should be brought forward to the uncertainty assessment. User Type: MO
11. **Multiple Conceptual Models** : The analysis of system data may often lead to different plausible interpretation of the system. Rather than settled for one most likely conceptual model, alternative conceptual models should be brought forward to task 2.7 Need for Alternative Conceptual Models? User Type: MO

References

1. Wright, J.F., Sutcliffe, D.W., Furse, M.T. 2000. Assessing the biological quality of fresh waters - RIVPACS and other techniques. ISBN 0 900386 62 2www.eamn.org (COST Action 626 web page) User Type: MO
2. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO
3. Environment Agency (DEFRA): Development of a Modelling and Decision Support Framework (MDSF) for Catchment Flood Management Planning: Vol 1 Procedures. http://www.mdsf.co.uk User Type: MO

2.5 Model Parameters

User Type: MO

Definition

Describe model parameters to be grouped, set to fixed values, or calibrated (with their likely range of values).

In this task a pre-selection is made of those parameters (a) that can be pre-defined (singly or in groups) using 'text book' or default values that will not usually need further adjustment, and those (b) that will be assessed by calibration (giving their likely range of values). An important aim is to reduce the number of free parameters to be assessed during model calibration, where a further reduction may be sought on the basis of sensitivity analysis.

Activities

- Areal subdivision
- Calibration parameters
- Parameters not calibrated

Introduction to activities

1. Model parameters will either be specified (held constant) or estimated during model calibration. In this task a pre-selection is made of those parameters that are intended to be assessed through calibration (with their likely range of values) and those that will be assessed beforehand (in this task) - using values from text books, previous studies, etc. The parameters intended for calibration will be evaluated further in the Task Select Calibration Parameters, where the most sensitive will finally be chosen. User Type: MO

Areal subdivision

User Type: MO

Divide modelled area into regions, cells, or bands in order to distribute parameter values across the area, by extrapolation, interpolation or zonation. The subdivision will usually reflect the spatial resolution and model boundaries defined in the task Model Structure and Processes.

Applicable methods:

- Visualisation and Tabulation
- Contouring
- Spatial Interpolation and Integration
- Correlation and Regression

- Zonation

Calibration parameters

User Type: MO

Identify the parameters that will possibly be estimated during calibration, and define realistic ranges and initial values.

Applicable methods:

- Contouring
- Zonation

Parameters not calibrated

User Type: MO

Identify the parameters that are not estimated through calibration, assess the values assigned to them, and describe the source for this assessment. Typically, the values for these parameters are estimated from field or laboratory studies. A sensitivity analysis may be undertaken.

Applicable methods:

- Visualisation and Tabulation
- Contouring
- Spatial Interpolation and Integration
- Correlation and Regression
- Surface Fitting
- Zonation

Other task aspects

Sensitivities and Pitfalls

1. **Interpolation** : Use of interpolation methods that do not exactly honour the data makes parameter assessment more difficult. User Type: MO
2. **Scales** : Use of inappropriate temporal or spatial scales makes assessment of model parameter values difficult. User Type: MO
3. **Parameters outside Observed Range** : Use of derived parameters in the model that are outside of the original observed range weakens the reliability of the parameter values. User Type: MO
4. **Assessment of Parameter Values** : Some parameters are difficult to quantify. e.g. due to experimental limitations or because they do not refer to measurable/actual ecological variables. User Type: MO
5. **Uncertain Parameters** : Use of parameters that are uncertain (due to experimental limitations or to

missing reliable data in monetary terms, such as willingness-to-pay functions for reduced contaminations of potable water or for amended ecologic habitats). User Type: MO

6. **Reprensentativeness of Parameters from Laboratory Experiments** : For reactive parameters, such as sorption partitioning coefficients and degradation rates and dynamics, the field scale effective parameters may vary significantly from those obtained from well-controlled laboratory experiments. User Type: MO

References

1. Jorgensen, S.E., Nielsen, S.N., Jorgensen, L.A. 1991. Handbook of Ecological Parameters and Ecotoxicology. Elsevier. Amsterdam, pp.1320.For abstracts from a workshop organised at the University of Mamur, Belgium to address the problem of parameter estimation see:http://www.fundp.ac.be/paeqann/call.htmlJorgensen, S.E. 1999. State-of-the-art of ecological modelling with emphasis on development of structural dynamic models. Ecological Modelling, 120, 75-96. User Type:
2. Singh, V.P.; D. A: Woolhiser (2002) Mathematical modeling of watershed hydrology, Journal of Hydrologic Engineering, July/August 2002, 270-292 User Type: MO

2.6 Summarise Conceptual Model and Assumptions

User Type: MO

Definition

Summarise the current understanding of the system in terms of verbal descriptions, graphical presentations, equations, governing relationships, and/or natural laws that purport to describe reality.

The description may include mass balance statements, estimates of parameter values and ranges and other relevant information from previous studies and/or the literature. It should be clearly stated what is known and unknown about the system. In doing so, it should be recognized that the conceptual model is an idealised or simplified representation of the current understanding of the system, and key aspects of how the system works. As such it is subject to simplifying assumptions. These assumptions are required because, typically, is it not possible to completely represent the system in a model, and partly because there is rarely sufficient data to fully describe the system.

Activities

- Model boundaries
- Geological framework
- Hydrological framework and stresses
- Human-induced factors
- Water budget
- Hydrogeological Framework Assumptions
- Processes Assumptions
- Parameterisation Assumptions

Introduction to activities

1. The assumptions used in developing the conceptual model may have implications for the quality of calibration and predictions. As such, interpretation of model results should be made with these assumptions in mind. User Type: MO

Model boundaries

User Type: MO

Describe the location and type of boundaries for the model area. Boundary types include specified flow, specified head and head-dependent flow. If transport is included, the boundary for the included species must also be included, e.g. source strength and temporal/spatial variation.

Geological framework

User Type: MO

Describe the geological units and corresponding hydrostratigraphic units, model layers and associated aquifer properties.

Hydrological framework and stresses

User Type: MO

Describe the recharge and discharge processes and dominant flow mechanisms. This includes the definition of the aquifer media type (porous medium, fractured, etc.) and groundwater-surface water interaction. Groundwater level measurements should be used to estimate the general direction of groundwater, the location of discharge and recharge areas and the connection between groundwater and surface water flow.

Human-induced factors

User Type: MO

Describe the location and type of human-induced factors such as drains pumping wells and sources of pollutions.

Water budget

User Type: MO

A water budget should be prepared from the field data to summarize the magnitude of inflows, outflow and changes in storage.See also activity: Water budget in task Model Structure and Processes

Hydrogeological Framework Assumptions

User Type: MO

Develop a comprehensive list of assumptions made in defining the following:- Extent of model area- Hydrostratigraphic units- Boundary conditions

Processes Assumptions

User Type: MO

Develop a comprehensive list of assumptions made in defining how the following processes are represented in the model:- Recharge processes- Unsaturated zone processes- Groundwater/surface water interaction- Preferential flow paths (macropores, fractures and/or fault zones)- Discharge processes- Solute transport and water quality

Parameterisation Assumptions

User Type: MO

Develop a comprehensive list of the assumptions made in defining the following:- Parameters that are specified as constants, including fixed parameter values- Parameters that will estimated by model calibration, including the likely range of fitted values.

Other task aspects

Sensitivities and Pitfalls

1. **Model Structure Error** : Improper representation of the model structure, processes and parameters (distributions and ranges) may be concealed in the conceptual model and may not become apparent until model calibration is attempted. User Type: MO
2. **Symbolic Language** : Use of the symbolic languages such as Energy circuits language and Systems Dynamic language User Type: MO

References

1. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO

2.7 Need for Alternative Conceptual Models?

User Type: MO

Definition

Review conceptual model to determine whether there is sufficient uncertainty over the model structure and processes to warrant the development and evaluation of alternative formulations.

The conceptual model should adhere to the principle of parsimony. That is, it should be as simple as possible, yet maintain sufficient complexity, based on current understanding of the system, to adequately represent the processes needed to fulfil the modelling objectives.Note that any scenarios specified in the Model Study Plan may require changes in the conceptual model.

Activities

- Evaluate need

Introduction to activities

1. Modelling results (in calibration and simulation) may depend critically upon the conceptual model. Thus, there is the need to know whether the conceptual model provides an appropriate representation of the system given the modelling objectives and data availability. User Type: MO

Evaluate need

User Type: MO

The conceptual model should be evaluated by considering the following:- Are all the processes required to fulfil the model objectives represented?- Is there significant uncertainty in the model structure and parameters to warrant the development of alternative conceptual models?- Are there any internal discrepancies in the conceptual model?

Other task aspects

Sensitivities and Pitfalls

1. **Conceptual Model Error** : If the conceptual model does not adequately describe the system, or does not include relevant features or processes due to a lack of data or understanding, then the model predictions may not be accurate.Inadequacies in the conceptual model may not be apparent at this stage of the modelling process, but may become more readily apparent during model calibration. User Type: MO

2.8 Process Model Structure Data

User Type: MO

Definition

Transform and/or organise the qualified data into a database for use in constructing the model.

Qualified data refers to pre-processed data that has been evaluated and deemed acceptable for use in the present study.

Activities

- Unit and datum transformation
- Manipulation and interpolation of data
- Database and format
- Import data

Unit and datum transformation

User Type: MO

Perform necessary calculations to transform the qualified data to consistent units and a consistent datum (in elevation, space and time). Hydraulic head may need to be reduced to a common density (freshwater) and temperature. Data originating from different time zones and/or referenced to current local time (summer/winter) may need to be harmonised.

Manipulation and interpolation of data

User Type: MO

Manipulate and interpolate the qualified data into continuous fields. This includes documentation of data and methods used.

Database and format

User Type: MO

Selection of a database and appropriate format for storage of the processed data. Consideration should be given to storing the model structure data in the same database structure as the system input and output data and the model results. This would simplify linking differences between model variants with their corresponding model outputs.

Import data

User Type: MO

Processed data is entered into a database

Other task aspects

Sensitivities and Pitfalls

1. **Effective Parameter Values** : Estimation of effective parameters values may be difficult on the specified units without model calibration. User Type: MO

2.9 Assess Soundness of Conceptualisation

User Type: MO

Definition

An evaluation of the credibility and suitability of the conceptual model based upon professional judgement.

A kind of internal quality assurance, where the modeller steps back from the computer and, based upon practical experience and sound reasoning, judges whether the conceptual model is flawed, or whether it accords with best knowledge and common sense and is suitable for the present study. Depending on the quality assurance procedure for the modeller's organisation this task will typically involve a review by the person(s) in the modeller's organisation responsible for internal quality assurance.

Activities

- Common sense?
- Conceptual model vs. objectives?
- Speculative or inadequate elements?

Common sense?

User Type: MO

- Are the magnitudes of hydraulic parameter values, inflows and outflows realistic?- Are projected flow paths consistent with the boundary conditions, hydraulic property contrasts and (for transport simulations) the observed extent of solute plumes?

Conceptual model vs. objectives?

User Type: MO

- Are the relevant processes included with sufficient complexity (e.g. should the unsaturated zone be represented in the model)?- Are there preferential flows and if so, how are they represented?- Is the proposed vertical discretisation consistent with observed vertical gradients, lengths of screened intervals on monitoring wells, hydrostratigraphy, and needed resolution (e.g. for solute transport/water quality simulations)?

Speculative or inadequate elements?

User Type: MO

- Are differences between inflows and outflows in the water budget consistent with the storage capability of the flow system?- Are boundary conditions well defined?- Is there data enough to define whether stream systems or reaches are gaining or losing?- Are the extents of solute plumes and contaminant source/sink terms well defined?- Is there site specific data available for parameters governing solute transport and water quality?

Other task aspects

Sensitivities and Pitfalls

1. **Uncertainty of Conceptual Model** : Identification of "weak-links" or uncertainties in the conceptual model will be important during calibration and interpretation of predictive simulations User Type: MO
2. **Need for Experienced Person(s)** : This task relies heavily upon the practical experience of the person(s) conducting the soundness assessment User Type: MO

References

1. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO
2. Stephen Merrett (1997): Introduction to the Economics of Water Resources. UCL Press, University College London (UCL), United Kingdom, Bristol, USA. User Type: MO

2.10 Code Selection

User Type: MO

Definition

Decide on appropriate modelling software that is consistent with the conceptual model and the study objectives.

Activities

- Code inventory
- Select code
- Code verification
- Code support

Introduction to activities

1. An appropriate model code and Graphical User Interface (GUI) must have the capability to adequately represent the essential features and processes necessary to fulfil the modelling objectives - including the assessment of scenarios. It is also important that the model code is verified and benchmarked against standard test problems. Other factors relevant to code selection include the available hardware platform, operating system, user support, modelling expertise and project budget, as well as the clients wishes and requirements. In some projects, the code to be used may be specified already in the Terms of Reference. Available complementary codes may also be required, including: - An updating method for forecasting applications- A precipitation model for design applications- Statistical tools for the interpretation of trends- Modules for specific pollutants
User Type: MO

Code inventory

User Type: MO

Unless a particular code has already been prescribed in the Terms of Reference, a survey of codes is made by looking into relevant reports and websites.

Applicable methods:

- BMW Toolbox

Select code

User Type: MO

Ensure that the code has the capability to represent the features of the conceptual model. This includes determining if the code is capable of simulating the relevant processes, such as:- Dimensionality of the flow system (2-D or 3-D, steady-state or transient flow)- Geometry and hydraulics of multiple aquifer and confining layers- Variability of parameters with space and time- Surface drainage- Groundwater/surface water interaction- Recharge processes (rainfall and evapotranspiration)- Boundary conditions- Saturated and/or unsaturated flow- Density-dependent flow- Representation of preferential flow (macropores or fractures) using an equivalent porous media, discrete fracture or dual porosity approach- Output of mass balance computations- Particle tracking - Solute transport and/or geochemical reactionsDepending on the numerical solution scheme, transport simulations may hampered by numerical errors or numerical dispersion, unless a very fine spatial and temporal discretisation is used. If solute transport (reactive transport in particular) is the focus of the modelling job, the possible transport solution(s) should be examined carefully.

Applicable methods:

- BMW Toolbox
- OpenMI

Code verification

User Type: MO

Check that the code has been verified so that its domain of applicability includes all the requirements of the modelling study.Ensure that the numerical results of the code have been compared with analytical solutions in order to demonstrate that it is free of round-off and truncation errors. Code verification is typically documented in the user's manual.

Applicable methods:

- BMW Toolbox

Code support

User Type: MO

Determine if the code developer offers technical support

Applicable methods:

- BMW Toolbox

Other task aspects

Sensitivities and Pitfalls

1. **Public Domain Code** : Some projects may require that a public domain code, as opposed to proprietary code, is selected due to specific review requirements.Many public domain codes have

undergone extensive peer review and case studies documenting their applicability and limitations are available in the scientific literature. Other public domain codes have not. User Type: MO

2. Complementary Modules : The selection of complementary tools (updating procedure, rainfall generator, etc.) or modules (e.g. water quality modules) will depend on the type of precipitation-runoff application. User Type: MO
3. Development of New Code : If a suitable code does not exist it may be necessary to develop a new code specifically for the project. This may be accomplished through modification of an existing code or by developing a new code from scratch. In either case, the code should be developed according to appropriate good practice guidelines and be verified (see Norm ISO 9000-3) User Type: MO
4. Numerical Codes : Numerical codes allow for the accurate simulation of complex problems. However, they demand more resources for setup and execution than analytical codes and the modeller may experience difficulties with numerical instabilities User Type: MO
5. Analytical Code : In general, analytical codes demand fewer resources than numerical codes for setup and execution. However, their applicability may be strongly dependent upon the skills of the modeller in conceptualising the system User Type: MO

References

1. The following URL provides key results for model selection:http://www.rbm-toolbox.net/bmw/index.phpNorm for software development:French standard: NF EN ISO 9000-3 (April 1999), Quality management and quality assurance standards. Part 3 : guidelines for the application of ISO 9001:1994 to the development, supply, installation and maintenance of computer software, 49 p.The following URLs provide also model inventories:- Register of Ecological Models- University of Kassel, Germany: http://eco.wiz.uni-kassel.de/ecobas.html- The Hydrological Operational Multipurpose System (HOMS) of the World Meteorological Organization: http://www.wmo.ch/web/homs/homshome.html User Type: MO
2. The following books provide some inventories of precipitation-runoff models:- Singh, V.P. (Ed.) (1995). Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, Colorado, 1130 p.- Singh, V.P. and Frevert, D.K. (Ed.) (2002a). Mathematical Models of Large Watershed Hydrology, Water Resources Publications, Highlands Ranch, Colorado, 891 p.- Singh, V.P. and Frevert, D.K. (Ed.) (2002b). Mathematical Models of Small Watershed Hydrology and Applications, Water Resources Publications, Highlands Ranch, Colorado, 950 p. User Type: MO
3. The following references provide information on existing updating procedures for streamflow forecasting:- Refsgaard, J. C. (1997). Validation and intercomparison of different updating procedures for real-time forecasting. Nordic Hydrology, 28, 65-84.- Yang, X. and Michel, C. (2000). Flood forecasting with a watershed model: a new method of parameter updating. Hydrological Sciences Journal, 45(4), 537-546. User Type: MO
4. The following reference provide information on the goals and results of the EU research project dealing with a standard for linking different models: HarmonIT (Open Modelling Interface and

Environment): http://www.harmonit.org User Type: MO

5. M. Blind and J.B. Gregersen (2004): Towards an Open Modelling Interface (OpenMI). The HarmonIT project. Proceedings of the iEMSs (The International Environmental Modelling and Software Society) Conference, 14-17 June, University of Osnabrueck, Germany User Type: MO

2.11 Report and Revisit Model Study Plan (Data and Conceptualisation)

User Type: MO

Definition

Report on Data and Conceptualisation, write associated parts of the Project Report, and draft an updated Model Study Plan for the next modelling step(s).

The report should cover the database and metadata, and also the conceptual model and its soundness. Consequences for the Model Set-up and subsequent steps should be described, and any revisions needed in the Model Study Plan should be drafted.

Activities

- Report writing
- Draft revised Model Study Plan

Introduction to activities

1. There are two aspects to report on: (1) the tasks already completed (Project Report) and (2) updates to the project plan for the next step(s) in the modelling process (Model Study Plan). User Type: MO

Report writing

User Type: MO

The following parts of the Project Report will be prepared:- Introduction (problem description, data availability, objectives, specifications)- Technical approach (overall methodology for performing the job)- ConceptualisationThe report should be in a suitable form for the task Review Data and Conceptualisation and Model Set-up Plan

Draft revised Model Study Plan

User Type: MO

Prepare in draft an updated version of the Model Study Plan, including an assessment of whether there is a need for additional data to complete the next Step. The project plans for the model step(s) until the next review will be described. In practice this implies that the next part of the Model Study Plan will be upgraded from the first version (prepared under the task Agree on Model Study Plan and Budget) using the improved knowledge obtained in the step Data and Conceptualisation, and providing greater detail on the proposed approach where appropriate. These revised project plans will be discussed during the forthcoming task

Review Data and Conceptualisation and Model Set-up Plan, and therefore any substantial changes as compared to the earlier version must be emphasised.

Other task aspects

2.12 Review Data and Conceptualisation and Model Set-up Plan

User Type: AU,MA,MO,SH,PU

Definition

Review the work carried out during the modelling step Data and Conceptualisation

This is an important opportunity to check that the project is progressing well towards meeting its objectives. The review will be based on: the report on Data and Conceptualisation; the draft update of the Model Study Plan; the Quality Assurance Plan and any other information provided by the modeller. It will provide the basis for:- A decision on formal approval of the work carried out in this modelling step, and- An approval of the detailed plans for Model Set-up as given in the revised Model Study Plan in the task Report and Revisit Model Study Plan (Data and Conceptualisation).

Activities

- Review Priorities
- Perform Review
- Stakeholder Feedback
- Manager Responds to Stakeholder Feedback
- Consensus
- Perform Modifications
- Approval of Modifications

Review Priorities

User Type: MA

The manager must- Confirm the decisions made in the Quality Assurance Plan, especially on the tasks and activities to be performed and the types of review required (see task Agree on Model Study Plan and Budget)- Identify an independent auditor for the audit/review/appraisal - Decide on the priorities of the tasks (weight factors) to be applied for the audit/review/appraisal.

Applicable methods:

- Checklist for Reviews/Audits/Appraisals

Perform Review

User Type: AU

Perform review as agreed in Quality Assurance Plan (Model Appraisal, Peer Review or Model Audit). If a scoreboard is used to evaluate the quality of the work, the auditor should assess the scores of the individual issues in the domain specific checklists.

Applicable methods:

- Peer Review
- Checklist for Reviews/Audits/Appraisals
- Model Appraisal
- Model Audit

Stakeholder Feedback

User Type: PU,SH

The stakeholders report feedback to the Report on Data and Conceptualisation. Furthermore, feedback to SIP (see method Stakeholder Involvement Plan) are relevant at this point, with suggestions of adjustments to the SIP for the next phase of the modelling. This could include:- Actions to further support common understanding- Clarification of team roles and responsibilities- Changes in participating stakeholders in working groups- Additional needs for information from general public and stakeholders. Stakeholders and general public should give feedback about needs for adjustment of preferred interaction and communication tools (according to SIP) to be used for the subsequent step until next stakeholder feedback in task 3.5 Review Model Set-Up and Calibration and Validation Plan (se method Interaction and communication ABC).

Applicable methods:

- Interaction and Communication ABC

Manager Responds to Stakeholder Feedback

User Type: MA

The manager answers comments from stakeholders on Report on Data and Conceptualisation and decides if changes are needed for the SIP (see activity Prepare Stakeholder Involvement Plan). The manager reports the comments and answers to both reviewers and modeller. Changes to the SIP are discussed with the modeller and included in the model study plan (SIP chapter).If necessary, the manager adjust selected interaction and communication tools to be used until next review task (see Method Interaction and communication Tools ABC).

Applicable methods:

- Interaction and Communication ABC

Consensus

User Type: AU,MA,MO

The auditor presents his conclusions and recommendations to the manager and the modeller. Together they decide on the conclusions and necessary actions to be taken as a consequence of the review- Whether the work has been carried out satisfactorily in its present form- Whether specific modifications to the work are required to be carried out by the modeller before proceeding to the next task- Whether unforeseen conditions have arisen so that the work has to return to the task Describe System and Data Availability or to previous steps in the modelling process- Whether any proposed changes to the Model Study Plan should be approved

Perform Modifications

User Type: MO

The modeller carries out the required modifications and makes the necessary modifications to the reporting in the Project Report.

Approval of Modifications

User Type: AU,MA,MO

The modifications made by the modeller are assessed by the manager. The manager may decide to contact the auditor, if required. If the modifications are accepted as satisfactory the modelling job proceeds with the next task. Otherwise the additional modifications have to be agreed upon and the previous activity is repeated.

Other task aspects

Sensitivities and Pitfalls

1. **Clarity of Objectives** : The objective of the modelling process and the requirements which the modelling must meet cannot be recorded clearly enough. A pitfall when setting up the modelling project is that the method of recording the results is not determined until later on in the modelling project. When a model is part of a chain, it is particularly important that all relevant requirements are specified beforehand (including the resolution, boundary conditions, uncertainty and scale). The scope chosen must be large enough to allow the boundary conditions to be independent of what takes place in the field of study. If the temporal and spatial scales of the problem have not be defined clearly enough, this will have consequences in the later phases of the modelling process. Consequently, the model scales may not be correspondent to the required answer. If the model scale chosen is too large, this will be translated in too general a schematisation, so that relevant details can no longer be derived from the results. The problem could be schematised away, for example. If the chosen model scale is too small, irrelevant small-scale variations will be disproportionately weighted, which can lead to non-optimal calibration for the large-scale variations. The user must be aware of the possibilities offered by the model. It occasionally occurs that a model is required to have more functionality than is possible (insufficient support in know-how, data, theory,

etc.). In practice, the target of a modelling process is often also formulated at a 'management' level. This sometimes leads to communication problems in the translation to the 'technical' model level. Consequently, the modelling does not provide the answer required by the client in the end. User Type: AU,MA,MO,PU,SH

2. Need for Good Conceptual Model : A sensitive point in this step is the construction of a good model concept. A wrong choice of processes and the comparisons which describe the process, can lead to errors in the model which cannot be traced at a later date. This can occur, for example, if essential processes (chemical, for example) or driving forces (discharges, for example) are ignored. As the modelling progresses, there is a risk that wrong choices in the model concept may become 'concealed' by the method of calibration. Another sensitive point is the construction of a very detailed model, while there is insufficient or no data available. In large, spatially organised models in particular, it is vital that the scale and the number of independent parameters (degrees of freedom) are chosen in accordance with the available data. If too many parameters are applied to a model, there is a risk of it appearing to work well (it follows the historical measurements) but that it is hardly or not at all suitable for interpolation or prediction. This can actually only be determined if adequate measuring data is available, i.e. with the right frequency in relation to the chosen time step. Measuring data is often interpolated in order to meet the temporal step of the model. The method of interpolation in particular can have major consequences. This must be taken into account upon construction of the model, as there is otherwise the risk that a model is constructed which cannot be calibrated. In a number of cases, incorrect estimation of a starting state (for example, the amount of pollution present), can lead to wrong conclusions. User Type: AU,MA,MO,PU,SH
3. Multiple Conceptual Models : Alternative models or conflicting models should be encouraged and applied whenever there is a need for evaluation of importance of uncertainty related to model structure and conceptualisation. It is better to try to validate alternative models, and maybe eliminate the ones that turn out to be non-behavioural, than blindly trust an arbitrarily selected model and assume that this model has no uncertainty related to model structure. In many cases the differences that alternative models produce are much more interesting, than the similarities in results. In this regard it should be noted that alternative and even conflicting models can be dealt with using HarmoniQuA and MoST. User Type: MA,AU,MO,PU,SH
4. Code Selection : Knowledge of the various model codes available is of great importance. Only too often however, the choice of model program is made because the modeller is familiar with that program. This does not necessarily mean that this is the most suitable program, of course. User Type: AU,MA,MO,PU,SH

Step 3: Model Set-up

Model Set-up involves transforming the conceptual model via the selected model code into a site-specific model. Spatial and temporal resolution must be selected to resolve the model area (model grid) and the simulation period. Boundary conditions have to be defined to describe internal stresses as well as the exchange between the model area and the surrounding environment. A major task in Model Set-up is the processing of data in order to prepare the input files necessary for executing the model. Also, minor alterations to the conceptual model may be made to improve how the model runs, but any major change would require a return to Step 2. Usually, the model is run within a Graphical User Interface (GUI) where many tasks have been automated. The GUI speeds up the generation of input files, but it does not guarantee that the input files are error free. The construction of the model is a very important task. If the model is erroneously or poorly constructed (e.g. input errors or bad representation of the outer boundary), the model may not be stable, the calibration may fail, or, even worse, may result in unrealistic parameter values. With unrealistic parameter values, the model simulation will be highly questionable. A quality check on the constructed model, including the input files, is therefore vital. A check on the input files is especially important for complex modelling jobs and if the GUI/model code is new to the modeller.

3.1 Construct Model

User Type: MO

Definition

Transform the conceptual model, using the selected model code, into a fully working trial model for the study area.

The task Construct Model may involve:- Transforming the already processed and qualified data into the specific format required by the selected code- Defining model grid and time stepping (discretisation in space and time)- Transfer of the conceptual model, input data and parameters into this framework using the selected model code- Implementation of model boundary and initial conditions, and input data that drive the modelConstruct Model is mainly a data processing task. Graphical user interfaces (GUIs) may be used to define set-up data and simulation parameters.

Activities

- Process set-up data
- Spatial discretisation
- Discretisation in time
- Parameter values
- Boundary conditions
- Initial conditions
- Simulation features
- QA of model set-up

Process set-up data

User Type: MO

Process all the data required for the model set-up according to the requirements of the selected model code

Applicable methods:

- Visualisation and Tabulation
- Contouring
- Spatial Interpolation and Integration
- Surface Fitting
- Thiessen Polygon Method
- Zonation
- Potential Evapotranspiration Estimation

Spatial discretisation

User Type: MO

In a numerical model, the continuum of parameters and processes in the system is represented by a discretised system consisting of finite difference cells or finite elements. The overall dimensions of the grid are determined by the conceptual model and the selected model type. Independent of the type of model grid used, factors that should be considered in determining the spatial discretisation (horizontal and vertical) of the grid include the scale of the processes to be represented, the variability of aquifer and transport parameters, the scale of input data and the desired scale of model output. Irregular grids or meshes are often used to provide increased resolution in some regions of the model area. A fine discretisation is often assigned to the area of interest with discretisation becoming coarser with increasing distance from this area. The increase in nodal spacing from areas of fine resolution to coarser resolution should not exceed 1.5 times the previous nodal spacing. Although finite elements are suited to complex geometries, the finite element mesh often becomes very complex and difficult to navigate in. For any numerical scheme the accuracy of the numerical solution is dependent on the grid resolution. To minimise numerical artefacts, like numerical dispersion, it is often necessary to use a finer spatial discretisation in transport modelling than that required for the flow simulations. The adoption of a fine spatial resolution is particularly important when steep concentration gradients are being simulated. The ideal way to determine the optimal spatial discretisation is to successively decreasing the grid dimensions, until no changes are observed in the model results. Finer grid resolution will increase the simulation time. If the simulation time gets too long and a coarser, and less accurate, grid must be used, the effects of the less accurate solution should be evaluated.

Applicable methods:

- Finite Element
- Finite Difference

Discretisation in time

User Type: MO

Transient simulations are used to analyse time-dependent problems, and produce a set of state variables (e.g. heads) for each specified time step. Steady-state simulations generate only one set of state variables and the results are independent of time. The accuracy of a transient solution is strongly dependent upon the assigned temporal discretisation. Ideally, small time steps should be used to ensure the numerical solution provides a better approximation of the partial differentiation equation. A balance must be achieved between the long run times, yet more accurate solution obtained using small time steps and the shorter run times and less accurate solution obtained when using large time steps. The sensitivity of the transient solution to the length of time steps should be tested. The choice of time step is particularly important in transport modelling, where too long time-steps may introduce significant numerical errors. Numerical oscillations may be indicative of using time steps that are too large.

Model structure

User Type: MO

Implement the model structure in the set-up data based on the conceptual model. Model structure may be handled either: a) according to selected model grids or b) in a separate spatial set-up database, often GIS-based programs/utilities are used for storing the spatial data (e.g. structures defining geological layers and lenses in GW, soil profiles and distribution codes and vegetation and crops in PR, cross sections in FF etc.). In case of b) the pre-processor (GUIs) for the selected model code calculates the "executable" model set-up data for the nodes based on selected options in model set-up data.

Parameter values

User Type: MO

Assign parameter values. Numerical models require that each node or element of the grid or mesh is assigned a value for each hydrogeological framework property (top and bottom elevation of layers or layer thickness), hydraulic parameters (hydraulic conductivity, transmissivity, storage properties) and transport parameters (porosity, sorption/desorption, dispersivity, diffusion, degradation). The framework, hydraulic and transport properties are commonly assigned to hydrostratigraphic units as defined in the conceptual model. The data and methods used in determining parameter distributions should be documented.

Boundary conditions

User Type: MO

Assign boundary conditions. Boundary conditions are constraints imposed on the model to represent the interaction between the model calculation domain and the surrounding environment. A distinction between external and internal boundary conditions can be made, both of which may vary with time. The type of boundary selected should be consistent with the conceptual model, and should be located and orientated consistently with the features it represents. Time-varying hydrological data need to be applied to those model features that represent stresses on the system (e.g. pumping wells, rivers, recharge, etc.). Inner and outer boundaries can be represented by - Constant head/concentration boundaries- Specified flow/flux boundaries for which the water flux/concentration is given. This includes no-flow boundaries- Constant gradient, where the hydraulic head/concentration gradient is kept constant- Head-dependent boundaries (flow only) for which a flux across the boundary is calculated by the model based upon specified values of head and conductance

Initial conditions

User Type: MO

Assign initial conditions. Initial conditions refer to the hydraulic head distribution prescribed throughout the model area for the beginning of a simulation. The steady state solution to a well posed problem is not dependent upon the initial conditions. Common approaches for assigning initial conditions to steady state models are to use either continuous fields of the topography or observed groundwater levels. The results of transient simulations are dependent upon the initial conditions. Typically, initial conditions in transient models are assigned using a steady-state head solution. An alternative approach for determining initial conditions in a transient model is to use a dynamic steady-state head solution, where boundary conditions are specified that are representative of average conditions and the transient model is run until the flow solution reaches equilibrium. If solute transport is included in the modelling job, the initial solute concentration distribution also has to be specified. Data on the solute concentration distribution are often sparse, and it may be necessary to start the simulation from solute free conditions.

Simulation features

User Type: MO

This activity involves describing the current simulation. It should include the following information: -start and end data of simulation period-hot-start file if initial conditions are read from previous simulation result file-time step control (initial and max) for different domains-flags and specification of solver options and parameters (e.g. max. number of iterations, iteration stop criteria etc.) Finally, the resolution of model output data and its storage must be defined in the simulation control parameters depending on the requirements and available disk space.

QA of model set-up

User Type: MO

Check the model input data by printing or plotting important input data (maps, cross sections, time series, specifications of parameters, options in the simulation file, etc.). Eliminate warnings and errors produced by the GUI in preparing executable model set-up data files ready for simulation.

Applicable methods:

- Visualisation and Tabulation

Other task aspects

Sensitivities and Pitfalls

1. **Start with Simple Model** : It should be realised that a model always is a simplification of reality and that adding more details in model set-up does not necessarily result in a better model. A fast execution time on available hardware, and requirements for available data quality and number of runs for calibration and simulations may not be met if the model grid or structure is too detailed, which could be critical. It is advisable to start simple and add more details (refinement of grid and/or model structure) and test execution time. User Type: MO
2. **Steady State and Transient Models** : In many cases it is beneficial to be able to run the model for

both steady state conditions and for transient conditions. Steady state simulation may be relevant for definition of initial conditions, inverse calibration and certain simulations, whereas transient simulations may be required for both calibration, validation and simulations. However, transition from steady state model to transient model is not straight forward. It is important to address consistency in boundary conditions, inputs- and predictions. User Type: MO

3. Data QA : Since model construction is fundamentally a data processing task, where available graphical user interfaces (GUI's) typically are used, it is important to carefully test the transfer of data by different QA measures (graphical outputs, reviewing warnings and errors produced by GUI in producing executable set-up data). Any assumptions or modifications required to refine the conceptual model during this transformation into the mathematical model should be fully documented, so it is transparent and reproducible User Type: MO
4. Check Model Code : Be critical with descriptions and advice in model code user manual. Better to test by input retrieval what the GUIs have exactly done rather than to trust any manual. User Type: MO
5. Experience with Model Code : Experience and knowledge with the selected model code in the model team from previous modelling studies is desirable in order to define set-up parameters and computational simulation parameters. Errors in the set-up task is more likely to occur if the model code and/or GUI are new to the modelling team. User Type: MO
6. Abiotic Boundary Conditions : Ensure appropriate abiotic boundary conditions are used so ecological simulations begin from a correct starting point. User Type: MO
7. Initial Conditions : In studies where long time scales are being considered it is crucial that initial conditions are accurately determined. If they are not then a sensitivity analysis should be undertaken. User Type: MO
8. Spatial and Temporal Resolution : Reduction of the spatial and temporal discretisation will not automatically result in better model results. A very fine grid may give the impression of a very detailed and therefore accurate model. Unless information is added on the right scale however, the only added value of a finer grid is its ability to prevent numerical errors. In combination with overly detailed parameterisation, a finer grid may even provide less information. User Type: MO

References

1. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO
2. Information about the various types of, in hydrologic-economic water models commonly used, GAMS optimisation solvers can be found on www.gams.com/sales/academicp.htm User Type: MO

3.2 Test Runs Completed

User Type: MO

Definition

Identify and resolve any problems in the constructed model (conceptualisation, set-up data, computational control parameters).

Select adequate test runs to demonstrate that the model converges appropriately, and that it runs smoothly and produces sensible outputs and with an appropriate execution time according to requirements in Model Study Plan. Initial parameter estimates from the conceptual model (parameterisation) are used for the test runs. The test does not assess the performance of the model in relation to target data and performance criteria. However, overall mass balance figures and the effects of imposed boundary conditions should be examined and the need for improvements in conceptualisation or construction considered, before the more time consuming calibration process is initiated.

Activities

- Establish log of model runs
- Select test runs
- Analyse results from test runs
- Decide actions re. identified problems

Establish log of model runs

User Type: MO

It is important that the modeller keeps a complete overview of the model runs, both successful and unsuccessful tests. This will help the modeller gain a detailed insight into the model and the modelled system, discuss problems with other experienced modellers, and if necessary, report any problems encountered to the model code developers. Although each model run may be reported in MoST, this may not be the most efficient strategy. Alternatively, a log file may be established in which details on each model run are recorded, and this can then be attached to MoST as an external file, and in this way included in the model journal. For the log to be of real value, it should be:- Detailed. The modeller should be able to trace back all adjustments made to the conceptual model, model structure data, parameter values, input data, boundary conditions etc. for all model runs. Major outcomes of the individual runs, including illustrative plots, may also be stored in the log file to provide an overview of the effects of the changes between different model runs, without having to analyse the model output files each time - Systematic. The overview may be easily lost if numerous simulations have been carried out and the log file has not been structured in a logical and systematic way. A well organised log file will also allow other modellers, not involved in the project, to get a detailed insight into the model and possibly continue work on the modelling job- Stored safely. The log file should be stored in a way that ensures the modeller and other team members can find it, and it can be accessed for future re-entries of the model job. To fulfil the requirements for the log file, it is recommended that a general structure on how to organise and store the necessary information is considered. A digital log file, that can be attached to MoST, should be strongly encouraged. Log files often take the form of hand-written papers that cannot be shared, and which often disappear during or immediately after the modelling job has been completed. Furthermore, the accessibility of the log to other project participants may be discussed, e.g., a separate log for Steps 3, 4 and 5 may be constructed and attached in the Review tasks of each step.

Select test runs

User Type: MO

If several domains are involved, a test run for each decoupled domain should be undertaken before the integrated (coupled) model is tested. For example, before testing a coupled surface and groundwater model, the surface water component (rainfall/runoff, overland flow and river flow) could be tested first, by omitting the groundwater model, and vice versa. If both steady-state and transient models are required, each version should be tested individually. For the transient model the test period should correspond to the entire calibration and validation period. If different alternative conceptual models are to be applied, a test run with each version should be undertaken.

Analyse results from test runs

User Type: MO

These analyses include an examination of the print files that correspond to the model results file.- Does the printed list of files, options, parameters, components etc. correspond to the intended?- Does the simulation print file contain warnings or errors which require further action or adjustment?- Do the listed boundary conditions correspond to those defined, have any been turned off?- Does the information on iterations show any severe problems with convergence?- Are any state variables adjusted during the run?Next step includes an examination of results, based on output retrieval and graphical display of test run results.- Are the simulated state variables, especially near boundaries, realistic?- Compare the overall results (e.g. mass balance) produced by the model runs with the one from the conceptual model.- Can the differences be addressed by the subsequent calibration process?- Are there any problems with input data, boundary conditions or model structure?

Applicable methods:

- Visualisation and Tabulation
- Spatial Interpolation and Integration
- Robustness
- Surface Fitting

- Aggregation
- Stability Test
- Mass balance
- Global behaviour

Decide actions re. identified problems

User Type: MO

If any problems were identified, it has to be decided how to address them. Several options are available: a) ignore the problems (if they have no practical impact on results when compared to performance criteria), b) adjust model construction (set-up data and simulation control parameters) possibly in a dialogue with the model code developer, c) if the problems can not be eliminated by adjusting the constructed model, then go back to conceptualisation and reconsider model structure, processes and parameterisation (communicate with both model code support and manager if this option is necessary).

Other task aspects

Sensitivities and Pitfalls

1. **Overview of Mass Balance** : Analysis of overall results (e.g. mass balance figures) may not be easy to assess at this point in the process, and may require a calibration of the model before it can be evaluated. User Type: MO
2. **Numerical Stability and Model Complexity** : Numerical problems are more frequent when dealing with complex models, feedback between domains etc. Solutions may interfere with the goals of the conceptual model User Type: MO
3. **Errors in Code** : Errors in the model code may be identified, but difficult to explain for model code developer User Type: MO
4. **Numerical Stability** : Numerical stability may depend on parameters, time step, stress data and initial conditions, so problems may arrive or disappear later in the process. User Type: MO

3.3 Specify or Update Calibration and Validation Targets and Criteria

User Type: MO

Definition

Calibration and validation datasets and accuracy targets should be proposed as measures for the acceptance criteria prior to model calibration.

This task re-examines the general approach to Calibration and Validation given in Task Determine Requirements (activities Overall quality, Model analysis, and Performance criteria), and then incorporated into the Model Study Plan. Decisions have to be made on which data to use as targets for calibration and validation tests of the calibrated model. Both representativeness, scale and quality of data, should be addressed for each step in the calibration strategy (e.g. steady state calibration, transient calibration, multi-domain calibration). The assessments here form part of the subsequent Report and Review tasks, and define the core approach that will be implemented in the next model step.

Activities

- Review calibration and validation proposals
- Select observation datasets
- Analyse quality of observations
- Performance criteria

Introduction to activities

1. The task includes further analysis of collected observation datasets. This is in addition to the data analysis and processing carried out in the step Data and Conceptualisation and the tentative plans for calibration and validation included in the Model Study Plan. Selection of relevant datasets is necessary in order to prepare adequate targets for the calibration, and reserve datasets for validation (see methods for Task Validation). Data required for model calibration and validation may include mass flux data (e.g. meteorological data, flow, mass transport) and state variables (e.g. head, water levels, water quality, soil moisture, species composition, population level, ecological status). The quality and representativeness of each data source and data point should be analysed with regard to the scale of the constructed model (particularly important when using automated calibration). If the distribution over the model area is "non-uniform", some data/datasets may be omitted to get a more even distribution of calibration and validation targets. The task includes the analysis of observation datasets in order to quantify uncertainty and determine calibration targets,

and the specification of calibration performance measures. User Type: MO

Review calibration and validation proposals

User Type: MO

The suitability of the calibration and validation procedures originally defined in task Determine Requirements (see guidance for activities Overall quality, Model Analysis and Performance criteria), developed in the modellers technical proposal, and incorporated into the Model Study Plan is reviewed in the light of knowledge gained during the model set-up. The guidance mentioned above is highly relevant, as is guidance on calibration and validation methods included in the Task Validation in step 4. This short activity is followed by more detailed consideration of the datasets available and the performance criteria to be adopted.

Select observation datasets

User Type: MO

Calibration data sets should be selected based upon the modelling objectives and quantity and quality of the available data. Models used to predict changes in groundwater levels, capture zones, changes in groundwater/surface water interaction and other boundary fluxes should be calibrated to both hydraulic head and flux data. Moisture content data are desirable if simulations include the unsaturated zone. Calibration data for models used to predict solute transport should include groundwater ages and/or water quality data. For steady state simulations the calibration data should be representative of average head and flow conditions. For transient conditions it may be necessary to consider temporal representativeness (e.g. daily values may not be relevant for monthly stress period, but should be averaged).

Analyse quality of observations

User Type: MO

The uncertainty of the calibration data should be quantified in order to determine how accurately the model can be expected to simulate observations and determine objective criteria for the weighting of calibration data. Hydraulic head possesses uncertainty due to measurement error, inaccurate borehole coordinates, data processing errors and loading effects such as changes in barometric pressure. Baseflow estimates can be obtained from stream discharge data. These flux estimates posses uncertainty due to temporal variations in groundwater/surface interaction. In general, model grid cells are much larger than the scale at which observations where made. This scale affect contributes to calibration data uncertainty because the actual location of the observations may not coincide with the point (grid node or grid centre) at which the head, flux or concentration is simulated. This uncertainty is further compounded by differences between actual and represented heterogeneity (model structure and parameterisation). Both single observations and time series should be analysed in order to eliminate data of poor quality or data that is not representative of the current stresses. Some observation datasets may be located too close to the model boundary, or too close to internal boundaries, to be used for calibration (e.g. boreholes with pumping). Measurement errors and uncertainties partly related to the scale and complexity of the constructed model, should be assessed to enable consideration of the required mean error and standard deviation. Data uncertainty is used in defining calibration targets with the following relationship:calibration target = observation +- a (Sob), where a is a weighting factor and Sob is the standard deviation of the observation.

Performance criteria

User Type: MO

Initial guidance on subjective and objective performance criteria has been given under Overall quality, Model Analysis and Performance criteria in Task Determine Requirements, but Calibration and Validation generally rely on using numerical performance measures to quantify how well observations are simulated by the model. A range of calibration performance measures are available, including: cumulative, mean, or period-maximum residuals (real, absolute, proportional, squared, weighted, etc), of various target variables (flows, levels, concentrations, etc) and functions or transformations thereof (instantaneous, means, maxima, etc), and over various durations (all or partial range of time steps). The various performance measures give different information on the model performance. Therefore, it is advisable to make use of several performance measures. The most appropriate performance measures for the model study are selected and performance criteria values defined. Further consideration of performance criteria is given under Specify Objective Function in Task Select Calibration Method. The performance criteria values should reflect the required model accuracy as defined in the task Determine Requirements as well as the data quality, uncertainty and representativeness. The model's ability to reproduce the observations must also be taken into account, e.g. steep concentration gradients cannot be reproduced in a coarse grid. While this activity is mainly concerned with quantitative performance criteria, qualitative criteria may be defined for use in assessing the soundness of the Calibration and Validation.

Applicable methods:

- Visualisation and Tabulation
- Aggregated Performance Indicators
- Standard Performance Measures
- Extreme-condition Test
- Event Validity
- Statistical Validation
- Qualitative Performance Measures

Other task aspects

Sensitivities and Pitfalls

1. **Point Scale versus Aggregated Scale** : If modelling considers "solute transport" uncertainties at point or grid scale is often too large, and the model's predictive capability may be limited to predictions at

a larger scale. In such a case formulation of calibration criteria should not be related to the single data points, but viewed in a more statistical way. However, such issues may be difficult to understand for end-users. User Type: MO

2. Support Scale : Observations (e.g. solute transport) may not be representative for the scale used in the constructed model User Type: MO
3. Poor Data Quality : Definition of performance criteria may be rather vague, if the data quality is poorly known. A modeller would try to omit "mysterious" data points, because "outliers" give problems with the overall performance, whereas resource managers would defend these data points. User Type: MO
4. Dependence on Boundary Conditions : If some of the selected target data are affected by imposed boundary conditions, they may be of little use in calibration-validation and could give problems. User Type: MO
5. Use a Variety of Target Data : Inclusion of as many different target data types as possible for each step should be attempted in order to reduce problems with non-uniqueness or "equi-finality"(different structures and parameter combinations give similar performance). Some data should be reserved for validation purposes. It is highly preferable that a model is calibrated to a range of distinct hydrological conditions (e.g. flow, head, mass flux etc.) and with a relevant suite of performance measures (e.g. mass balance, state, flux, concentration etc.) applied for each step in the calibration strategy (e.g. steady state, transient, solute transport). If there are areas of special interest the observation data from that area should be densely represented. Data sets from stations with long uninterrupted time series of good quality should be preferred. User Type: MO
6. Use a Variety of Target Data : Inclusion of as many different target data types as possible for each step should be attempted in order to reduce problems with non-uniqueness or "equifinality" (different structures and parameter combinations give similar performance). Some data should be reserved for validation purposes. Most of the time, precipitation-runoff models are calibrated against a single variable (streamflow). In the case the model intends to have several outputs (soil moisture, water head, pollutant concentrations), the model can be calibrated with a relevant suite of performance measures applied for each step in the calibration strategy. Preferable are data sets from stations with long uninterrupted time series of good quality. User Type: MO
7. Weighting of Observation Data : When observation data is used unweighted, i.e. all residuals contribute equally to the performance measure, areas with clusters of observations will dominate the calibration measure and lead to an unbalanced calibration.If the observation values differ greatly, as is often the case in concentration measures, there is a risk that a peak in the observations will be disproportionately weighted. User Type: MO
8. Steady State Model : Nature is a dynamic system and a true steady state situation is never experienced. Great care must thus be taken when calibration data for a steady state model is selected, especially in systems with great inertia (long-term 'memory'). Often it may be desirable to average observations over a longer time period, rather than rely on an 'average hydrological year'. User Type: MO

References

1. Nash, J.E. and Sutcliffe, J.V. (1970). River flow forecasting through conceptual models. Part I - A discussion of principles. J. Hydrol., 27(3), 282-290. User Type: MO

3.4 Report and Revisit Model Study Plan (Model Set-up)

User Type: MO

Definition

Report on Model Set-up, write associated parts of the Project Report, and draft an updated Model Study Plan for the next modelling step(s).

Describe how the conceptual model has been implemented, linking basin characteristics with model structure, e.g. discretisation, boundary conditions, parameter values. Present results of test simulations using steady state and transient inputs. Give overall balances and quantitative performance criteria to provide a clear basis for reviewing Model Set-up and defining the Calibration and Validation procedures. Update the project plans for the next modelling step Calibration and Validation, describing the datasets to use and the accuracy (performance criteria) required in the calibrated model.

Activities

- Report writing
- Draft revised Model Study Plan

Introduction to activities

1. There are two aspects to report on: (1) the tasks already completed (Project Report) and (2) updates to the project plan for the next step(s) in the modelling process (Model Study Plan). User Type: MO

Report writing

User Type: MO

The appropriate parts of the Project Report will be prepared. This should be in a suitable form for the task Review Model Set-up and Calibration and Validation Plan.

Draft revised Model Study Plan

User Type: MO

Prepare in draft an updated version of the Model Study Plan, including an assessment of whether there is a need for additional data to complete the next Step.The project plans for the model step until the next review will be described. In practice this implies that the next part of the Model Study Plan will be upgraded from its current version (agreed under the task Report Data and Conceptualisation and Model Set-up Plan) using the improved knowledge obtained through Model Set-up, and providing greater detail on the proposed approach where appropriate. These revised project plans will be discussed during the forthcoming task Review Model

Set-up and Calibration and Validation Plan, and therefore any substantial changes as compared to the earlier version must be emphasised.

Other task aspects

3.5 Review Model Set-up and Calibration and Validation Plan

User Type: AU,MA,MO,PU,SH

Definition

Review the work carried out during Model set-up

This is an important opportunity to check that the project is progressing well towards meeting its objectives. The review will be based on the report on Model Set-up, the draft update of the Model Study Plan (previewing Calibration and Validation and suggesting calibration stop criteria and performance criteria), the Quality Assurance Plan, and any other information provided by the modeller. The review will be conducted to assess the quality of the work and will form the basis for:- A decision on the formal approval of the work carried out in this modelling step, and- An approval of the detailed plans for Calibration and Validation as given in the revised Model Study Plan in the task Report and Revisit Model Study Plan (Model Set-up).

Activities

- Review Priorities
- Perform Review
- Stakeholder Feedback
- Manager Responds to Stakeholder Feedback
- Consensus
- Perform Modifications
- Approval of Modifications

Review Priorities

User Type: MA

The manager must- Confirm the decisions made in the Quality Assurance Plan, especially on the tasks and activities to be performed and the types of review required (see task Agree on Model Study Plan and Budget)- Identify an independent auditor for the audit/review/appraisal - Decide on the priorities of the tasks (weight factors) to be applied for the model appraisal/peer review/model audit.

Applicable methods:

- Checklist for Reviews/Audits/Appraisals

Perform Review

User Type: AU

Perform review as agreed in Quality Assurance Plan (model Appraisal, Peer Review or Model Audit). If a scoreboard is used to evaluate the quality of the work the auditor should assess the scores of the individual issues in the domain specific checklist.

Applicable methods:

- Peer Review
- Checklist for Reviews/Audits/Appraisals
- Model Appraisal
- Model Audit

Stakeholder Feedback

User Type: PU,SH

The stakeholders provide feedback to the report on Model Set-up. Furthermore, they may provide feedback on the SIP (see method Stakeholder Involvement Plan), with suggestions for its adjustment for the next phase of modelling. This may include:- Actions to further support common understanding- Clarification of team roles and responsibilities- Changes in participating stakeholders in working groups- Additional needs for information from general public and stakeholders. Stakeholders and the general public should give feedback on the needs for adjustment of the interaction and communication tools (according to SIP) to be used for the subsequent step until next stakeholder feedback in task 4.13 Review Calibration and Validation and Simulation Plan(see method Interaction and communication ABC).

Applicable methods:

- Interaction and Communication ABC

Manager Responds to Stakeholder Feedback

User Type: MA

The manager responds to comments from stakeholders on the Model Set-up report and decides if it is necessary to change the SIP (see method Stakeholder Involvement Plan). The manager reports on these comments and responds to the reviewer(s) and modeller. Changes to the SIP are discussed with the modeller and included in the model study plan (SIP section). If necessary, the manager adjusts the selected interaction and communication tools that will be used prior to the next review task (see Method Interaction and communication Tools ABC).

Applicable methods:

- Interaction and Communication ABC

Consensus

User Type: AU,MA,MO

The auditor presents his conclusions and recommendations to the manager and the modeller. Together they decide on the conclusions and necessary actions to be taken as a consequence of the review- Whether the work has been carried out satisfactorily in its present form- Whether specific modifications to the work are required to be carried out by the modeller before proceeding to the next task- Whether unforeseen conditions have arisen so that the work has to return to the task Construct Model or to previous steps in the modelling process- Whether any proposed changes to the Model Study Plan should be approved

Perform Modifications

User Type: MO

The modeller carries out the agreed modifications and makes the necessary changes to the Project Report.

Approval of Modifications

User Type: AU,MA,MO

The modifications made by the modeller are assessed by the manager. The manager may decide to contact the auditor. If the modifications are satisfactory then the modelling job can proceed to the next task, otherwise additional modifications have to be agreed upon and the previous activity is repeated.

Other task aspects

Sensitivities and Pitfalls

1. **Single-loop and Double-loop Learning** : As provoked by Argyris (Argyris, 1991) most people do not know how to learn, and those that many assume to be the best at learning are, in fact, not very good at it. Well educated, high-powered, high-commitment professionals (may it be managers, modellers or stakeholders) who occupy key leadership positions in the decision making process, are good at single-loop learning, but often bad at double-loop learning. Single-loop learning is to pay attention to e.g. the model performance by comparison with specified performance criteria, and to act if this is not the case or simply to check that tasks have been carried out properly according to the specifications. Double-loop learning is the more difficult question, not only why is the performance set at this specific value, which is difficult to meet by this specific model, but to explore whether or not some other performance criteria could be more relevant, or whether the solution to a problem should be found in a previous task and not in the present task or step. An example could be in a wrong conceptualisation, which results in a chain of problems later on in calibration and validation.
User Type: AU,MA,MO,PU,SH

References

1. Argyris, C. (1991) Teaching smart people how to learn. In: Wendell, L.F., C.H. Bell and R. Zawacki

(Eds) Organizational development and transformation. McGraw-Hill 2000, pp. 295-305. User Type: AU,MA,MO,PU,SH

Step 4: Calibration and Validation

This step is concerned with the process of analysing the model that was constructed during the previous step in terms of calibrating the model and testing its performance against independent field data through validation tests. Model calibration is the procedure of adjustment of parameter values to reproduce the response of reality within the range of accuracy specified in the performance criteria. Model validation is the substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model. The credibility of a site-specific model's capability to make predictions about reality must be evaluated against independent data. In designing suitable model validation tests a guiding principle should be that a model should be tested to show how well it can perform the kind of task for which it is specifically intended. Finally the reliability of model simulations for its intended domain of applicability is assessed through uncertainty analyses and described so that the documented scope of model use and the associated limitations are made explicit.

4.1 Specify Stages in Calibration Strategy

User Type: MO

Definition

Subdivision of the entire calibration process into sub-steps

The task describes the process of focusing and enhancing the overall calibration process of a model, by splitting up the entire calibration process into a selected number of finite sub-steps. The subdivision may involve "decoupled" domains, sub-area calibration or a split into a steady state and a subsequent transient calibration step. The process may require some "iteration". The final step should be done with the fully "integrated model".

Activities

- Process calibration data
- Sub-area calibration
- Steady-state and transient calibration

Process calibration data

User Type: MO

Process any additional time-series data necessary to conduct the planned calibration strategy, extending the inventory of data prepared in Task Collect and Process Raw Data (Activity Evaluate pre-processed data) to cover any new sub periods of time-series data.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Contouring
- Spatial Interpolation and Integration
- Correlation and Regression
- Surface Fitting
- Aggregation
- Infilling (temporal)
- Zonation

Sub-area calibration

User Type: MO

Selecting one or more sub-areas and setting up sub-model for those areas is a feasible way to start with selected representative areas in the calibration process. Hereby, higher speed and better understanding of different parameters may be obtained, before runs with the heavy model are performed. Also scale issues may be addressed by running such pilot models, e.g. required grid scale in the model.

Steady-state and transient calibration

User Type: MO

Perform a calibration by combining steady-state and transient calibration methods. Transient models differ from steady-state models in that the solution at a given time is dependent upon initial conditions, whereas the results of a well-posed steady-state model are largely independent of the initial conditions. Typically, the initial conditions in a transient model are specified based upon the results of either a static steady-state or dynamic steady-state solution representative of some average conditions. Furthermore, automated calibration may not be feasible for complex models running under transient conditions. This problem may be overcome through automated calibration of a steady-state in order to obtained parameter estimates and initial conditions to be used in trial-and-error calibration of a transient model.

Other task aspects

Sensitivities and Pitfalls

1. **Sub-step Calibration** : It may be difficult to determine appropriate boundary conditions for sub-step calibration. User Type: MO
2. **Decoupled Calibration** : The calibration of an integrated model by "decoupling" of interacting domains into individual domain models may require an iterative approach where all domains undergo recalibration based upon the response of a single domain. It may be necessary to complete the entire process / all steps two or several times User Type: MO
3. **Iterations between Steps** : For all methods it is important to allow enough iteration between the single steps in order to incorporate the feedback mechanisms. Some parameters may be important for overall performance criteria (like mass or water balance), but some times overall performance to mass balance, can only be addressed by the integrated model. Selection of appropriate calibration criteria for each sub-step is required User Type: MO
4. **UZ-SZ De-coupling** : An example, where de-coupling between different processes within the GW domain is often used is between unsaturated and saturated zones where the simulated flux through the unsaturated zone is used to specify boundary condition fluxes in the saturated zone model. Similarly, calibration of solute transport models is typically an iterative process where the results of a calibrated flow model are used to define the flow field for the solute transport model. Calibration of the solute transport model may require recalibration of the flow model and input of the re-calibrated flow field in subsequent transport simulations. User Type: MO

5. **Link between Hydrology and SE** : Feed back loops may exist between hydrological models and socio-economic models (e.g. negotiations between water suppliers and farmers or simulation of markets for water rights). In such case the parameters determining the interactions between the two types of models (data exchange) should be identified and calibration may be an iterative process.
User Type: MO

References

1. Sonnenborg, T.O., Christensen, B.S.B, Nyegaard, P., Henriksen, H.J. and Refsgaard, J.C. (2003) Transient modeling of regional groundwater flow using parameter estimates from steady-state automatic calibration. JHydrol, 273, 188-204 User Type: MO

4.2 Select Calibration Method

User Type: MO

Definition

Select a parameter estimation methodology for model calibration

After model set-up, selected model parameters can be estimated by calibration. These calibration parameters are not accurately known in advance, but can only be broadly estimated from literature or previous experience. By adjusting them systematically to minimise differences between model outcomes and field observations, a better model is achieved. Calibration can be done manually or using automatic optimisation techniques. It can indicate problems in the model structure, but even a good fit does not guarantee a good model. Parameters can compensate for each other, and different data sets may suggest different combinations.

Activities

- Specify Objective Function
- Manual or automatic calibration?
- Parameter optimisation in code?
- Optimisation method and tool
- Couple an optimisation module to code

Introduction to activities

1. This is a difficult task. If you are very experienced, you will have a clear picture of what this task includes. Otherwise, plan all activities (if available methods allow) in this order:- Select/specify objective function- Choose between manual and automatic calibration- Determine whether the code provides some parameter optimisation method(s)- Choose an optimisation tool and method- Couple an optimisation module to your model User Type: MO

Specify Objective Function

User Type: MO

During calibration, a description will be made, in some manner, of the differences between the field observations and the model results, in the form of an objective function. The essence of the objective function is that its value decreases along with the decreasing deviations between the field observations and model results. Minimisation of the objective function is therefore the target during calibration. While this is reasonably simple in the univariate case, it soon becomes impossible to keep track of the situation when a number of variables need to be optimised simultaneously.To define an objective function the following steps have to be defined in order to come from many observations and many model outcomes to a single measure for the 'fit' between model and observations:- At the level of a single observation: define a distance between a single observation of some variable at some point in time and the associated model outcome;- Combine these distance at the point level for the whole area (in 1D, 2D or 3D) to a distance at the area level;- Combine the distances at the area level in case of a dynamic model to a distances for a single variable- In the multi-variate case (more variables with observations): combine the distances for various variables to a single distance between model and real system (as it is known by the observations).Several different approaches can be followed for the first step (yk as the kth observation and xk as the model result of that variable at the same point in time):- Residuals: ek = |yk - xk|- Relative error: ek = $(yk/xk -1)^2$- Squared residuals: ek = $(yk - xk)^2$For the second step one can combine the results ek of the first step by defining these criteria:- Averaging over time:- Using the maximum ek: Combining these criteria to a single model objective function can by averaging over the variables or using the criterion of the worst fitting variable, but some form of scaling has to be used here, if the variables have different ranges, e.g. combining a potato production in tons per ha with the starch content as fraction of dry weight requires scaling. Dividing by the variability can do the latter. This approach will lead to a series of different objective functions. Preference for step 1 is the residual and for step 2 and 3 averaging, because the relative error and the sum of square residuals is very sensitive for outliers, which is not often a desirable property. Nevertheless this is a frequently used 'norm', because it has desirable statistical properties and it can easily transformed in uncertainty boundaries.

Manual or automatic calibration?

User Type: MO

The use of automated statistically based calibration routines, such as those provided by PEST and UCODE, quantify the uncertainty in parameter estimates and provide the statistically most appropriate solution for the given input parameter. As such, automated calibration is preferable to trial-and-error calibration. In some cases automated calibration may, however, not be feasible for complex models running under transient conditions. This problem may be overcome through automated calibration of steady-state conditions in order to obtain parameter estimates and initial conditions to be used in trial-and-error calibration of a transient model.

Applicable methods:

- Automatic Optimisation
- Manual Optimisation

Parameter optimisation in code?

User Type: MO

Some model codes provide tools/functionality for automatic calibration. Even if not the best algorithms are used, it is preferable to use (one of) these for calibration.If there are more optimisation algorithms available, choose the best (based on experimentation by calibration of the model or by experience).

Optimisation method and tool

User Type: MO

If one chooses for automatic calibration, a method for (parameter) optimisation has to be chosen. Some advice on this choice is given in the introduction of the methods in this tasks and, further, several methods are indicated briefly. Advice of an expert can help to find the best or most feasible method and tool. Several universal stand-alone optimisation tools are available, e.g. PEST or UCODE.

Applicable methods:

- Genetic Algorithms
- Pure Random Search
- Quasi-Newton methods
- Direction-set methods
- Automatic Optimisation
- Controlled Random Search
- Simulated annealing
- Multistart and Clustering Methods
- Manual Optimisation
- Simplex method
- Conjugate gradient methods

Couple an optimisation module to code

User Type: MO

Technically seen, it can be a difficult task to actually couple a method for (parameter) optimisation to a model code. Start with using guidance provided with the model code (manuals and other). Use expertise (if available) on the method and tool and expertise on the model code to perform this activity successfully.

Other task aspects

Sensitivities and Pitfalls

1. Sufficient Calibration Data : Ensure that the quantity of the (observed) data, to be used in calibration, allows the use of a specific method of parameter estimation. User Type: MO
2. Not Curve Fitting : Do not confuse calibration with 'curve fitting', because calibration uses all information available on the calibration parameters, including info on its statistical distribution, while curve fitting does not use any bounding info on parameter values. User Type: MO
3. Iteration Stop Criteria : Elimination of the numerical nodal divergence should be the preferred iteration stop criteria for model convergence. Otherwise the convergence is not reached and the solution gets

inaccurate. This inaccuracy may be fatal in automatic model calibration based on multiple nonlinear regression analysis (PEST, UCODE and others). The latter calculates variation of object function due to small parameter perturbations which requires high precision of state functions (head, flux, concentration etc). In general, the magnitude of various errors (approximation error of the numerical scheme, spatial and temporal resolution error, numerical instability, insufficient convergence) should be much less than the object function otherwise the calibration will/may be derailed. User Type: MO

References

1. http://www.parameter-estimation.com/ http://www.awra.org/jawra/keywords/keymodelcalibration.htmhttp://gms.watermodeling.org/html/groundwater-calibration.htmlhttp://www2.hwr.arizona.edu/eoshome/modelcalibration/model_main.html http://www.mp.usbr.gov/sccao/sld/Plan_formulation_report/Appendices/Attachment_G1.1_complete.pdfhttp://www.ems-i.com/gmshelp/Model_Calibration/Model_Calibration.htm http://water.usgs.gov/nrp/gwsoftware/modflow2000/WRIR98-4005.pdf Gan, T.Y., Biftu, G.F., 1996. Automatic calibration of conceptual rainfall-runoff models: optimization algorithms, catchment conditions, and model structure. Water Resources Research 32(12), 3513-3524.Franchini, M., Galeati, G., 1997. Comparing several genetic algorithm schemes for the calibration of conceptual rainfall-runoff models. Hydrological Sciences Journal 42(3), 357-379.Thyer, M., Kuczera, G., Bates, B.C., 1999. Probabilistic optimization for conceptual rainfall-runoff models: a comparison of the shuffled complex evolution and simulated annealing algorithms. Water Resources Research 35(3), 767-773. User Type: MO

4.3 Define Stop Criteria

User Type: MO

Definition

Define one or more criteria to determine when to stop calibration.

In many cases quantitative goals in calibration are not fully met, especially in the multi-variate case, where more variables simultaneously have to fit with observed data. Other stop criteria should prohibit never-ending calibration and allow the introduction of other more subjective criteria if necessary.

Activities

- Calibration resources
- Calibration end date
- Maximum number of model runs
- Objective function value
- Parameter values
- Combined criteria

Calibration resources

User Type: MO

Specify the calibration resources. This includes all tasks and resources (computer, man-hours, expertise) associated with the calibration process.

Calibration end date

User Type: MO

In the model study plan some time schedule should facilitate defining a date when calibration should be completed. Use this date.

Maximum number of model runs

User Type: MO

Depending on the model, the calibration method and data availability (system observations), a maximum number of runs should be chosen. This varies substantially, typically several tens (for complex models) to many thousands of runs (for simple models). The maximum number of model runs may also be used as a pause to allow the modeller to assess how calibration is progressing. If all appears well, the maximum number could be increased to allow calibration to continue. Alternatively some manual adjustments to the parameters could be introduced, and the calibration restarted.

Objective function value

User Type: MO

Specify a stop criterion for the objective function, which may be simply a target value for the objective function during calibration. However, for many functions (e.g. mean square error) it is not possible to define what the minimum should be (it depends on the data and the model as well as the parameters). Thus the size of the change in function value towards an apparent minimum is more relevant (e.g. stop calibration when the objective function is changing by less than 0.5%). See also guidance on performance criteria in Task Determine Requirements and Specify or Update Calibrations and Validation Targets and Criteria.

Parameter values

User Type: MO

As with the objective function, the size of change in value of each parameter as the objective function tends towards an apparent optimum may be specified as a stop criterion. This can stop the 'ever decreasing circles' that some optimisation methods tend to follow in search of an exact minimum of the objective function. If the change in all parameter values is small, the optimum values will effectively have been found.

Combined criteria

User Type: MO

The best approach uses a prioritised list of stop criteria, e.g.:- If (date after Calibration end-date) then stop- Else if (resources used exceed Calibration resources) then stop- Else if (No. of model runs exceeds Maximum no. of model runs) then stop- Else if (Change in objective function less than specified) then stop- Else if (Change in parameter values less than specified) then stop- Else continue calibration

Other task aspects

Sensitivities and Pitfalls

1. Do not spend all Project Time on Calibration only : If this task is not completed appropriately, there will be a risk to continue calibration too long, leaving insufficient time for the remaining activities of the model study. User Type: MO
2. Trial and Error : This priority scheme does not reflect normal practices, as calibration often is a trial and error process with typically some of the following doings: switching from calibration methods, choosing other calibration parameters, choosing other preset values of the objective function, etc.Nevertheless, modellers are advised to write down some kind of scheme to stop the calibration process. User Type: MO
3. Need for Expert Judgement : It may not be possible to calibrate all variable to the same level.

Therefore, expert judgement is usually required to decide on the most important output variables and concentrate on calibrating these. User Type: MO

4.4 Select Calibration Parameters

User Type: MO

Definition

Determine which parameters (and other model input, e.g. decision variables) will be used for calibration and which will be kept constant for all calibration model runs

Many models have large numbers of parameters, which may or may not be spatially distributed and/or correlated. In virtually all cases, the amount of field data does not permit that all parameter will be optimized, however. Consequently, the number of parameters to be optimized must be reduced in one way or another, by choosing which parameters (or combination thereof) are to be optimized. This can be done in many ways, by including the 'well known' parameter values as known constants, by making groups of parameters values equal to one another (zoning) or by assuming a (geostatistical) relationship between parameters. A preliminary assessment of the parameters to fix should already have been made in Task Model ParametersThe choice of parameters to be optimised can now be refined, based on the results of a sensitivity analysis. The modeller also often has the expertise required to choose the right parameters for calibration purposes. On the one hand, they must have considerable influence on the final model results and, on the other hand, they must be visible throughout the measurements.

Activities

- Decide selection method
- Use expert judgement
- Perform sensitivity analysis

Introduction to activities

1. The activities within this task consist of a decision whether to use expert judgement or sensitivity analysis to select which parameters that will be adjusted in the calibration process (free parameters), and which that will be kept constant. The number of free parameters should not be too high. User Type: MO

Decide selection method

User Type: MO

Decide whether to use expert judgement or sensitivity analysis. Very experienced users of a specific model will probably know which model input (initial conditions, parameters, sometimes also decision variables) the model is most sensitive to, and may use this expertise to select calibration parameters. Otherwise, a numerical or analytical sensitivity approach may be adopted, though the analytical approach is seldom possible as it requires a model that can be solved analytically. There are several numerical sensitivity methods to choose from. The simplest method is 'Individual variation of a number of assumedly independent factors (parameters and sometimes other input)'. Major disadvantages of this method are that it is time consuming and that it neglects interaction effects, where model response to varying some inputs depends on the values of other inputs. Most modellers can benefit from advice by mathematicians/statisticians when choosing a sensitivity method.

Applicable methods:

- Resampling Techniques
- Response Surface Method
- Regionalized Sensitivity Analysis
- Monte Carlo Simulation
- Parameter Ranges in Sensitivity Analysis
- Sensitivity Analysis

Use expert judgement

User Type: MO

Describe for which model input (initial conditions, parameters, sometimes also decision variables) the model is rather sensitive and for which the model is insensitive.The point of departure for this analysis is the preliminary selection made in the Task 'Model parameters'.

Perform sensitivity analysis

User Type: MO

This is a complex activity, typically consisting of the following sub-activities: - Select sensitivity analysis method (from the methods provided here or other)- Define a quantitative sensitivity measure, for example the partial derivative of model outcome to each parameter (derived at some nominal parameter value), or the respective coefficient in a multivariate regression of model outcomes on parameter values (over global or local parameter ranges).- Run sensitivity analysis on the pre-selected free parameters (defined in Task 2.5, Parameterisation), with the other parameters set to their chosen fixed values- Select the most sensitive parameters for calibration, and define suitable fixed value for the other parameters, reducing the number of free parameters for the subsequent calibration task.If the model equations can be solved analytically, it may be possible to find the partial derivatives of model outcomes directly, but usually the sensitivity measures can only be determined numerically by successive model simulations.

Applicable methods:

- Resampling Techniques
- Response Surface Method
- Regionalized Sensitivity Analysis

- Monte Carlo Simulation
- Parameter Ranges in Sensitivity Analysis
- Sensitivity Analysis

Other task aspects

Sensitivities and Pitfalls

1. **Important Task** : Choosing the wrong calibration parameters will make calibration impossible or very difficult, with ambiguous calibration results. Skipping this task is only allowed when the modeller is very familiar with the model code, and applied this model code to similar problems as the problem at hand and under similar conditions (climate, environment, etc.). User Type: MO
2. **Limitation of Sensitivity Analysis** : Don't forget that sensitivity analysis takes the model structure and boundaries for granted. User Type: MO

References

1. Saltelli, A., Chan, K., Scott, M. (2000) Sensitivity Analysis. John Wiley & Sons publishers, Probability and Statistics series. User Type: MO
2. Saltelli, A., Tarantola, S., Campolongo, F. and Ratto, M. (2004) Sensitivity analysis in practice: A guide to assessing scientific models. John Wiley & Sons publishers User Type: MO

4.5 Parameter Estimation

User Type: MO

Definition

Estimate parameter values through calibration

This is a very complex task, in which the model (or a part thereof) is run successively with one or more parameters altered, either manually or automatically (according to a chosen algorithm), in order to optimise model performance with respect to some chosen criteria. Often, the task has to be performed several times. It is important to be aware that an uncalibrated model may not be very useful, but also that a well calibrated model does not always make sense for the system or problem at hand.

Activities

- Calibrate the model
- Monitor calibration performance
- Calibration measures versus stop criteria
- Evaluate parameter estimates

Calibrate the model

User Type: MO

In this activity, differences between model outcomes and system observations (field measurements), usually expressed in a single measure (the objective function), are minimised using the model as a tool and the parameters as arguments. Previous tasks will have defined, for each stage in the calibration process: - An optimisation method (task Select Calibration Method)- The objective function to optimise (task Select Calibration Method)- Stop criteria (task Define Stop Criteria)- Calibration parameters, also called 'calibration handles' and sometimes including other uncertain inputs (task Select Calibration Parameters)- Objective and subjective performance measures (for instance 3 to 4 thereof) that may be used to assess the calibration results (task Specify or Update Calibration and Validation Targets and Criteria)Prior experience and a manual or specific guidance for the calibration method and any software will usually be needed to perform this task. A record of progress towards a calibrated model, including values of the parameters, objective function and other performance measures, should be maintained in the model run log established in Task Test Runs Completed. This run log may then be attached to the Model Study Journal. Further guidance on these aspects is given under subsequent activities in this task.

Applicable methods:

- Visualisation and Tabulation

- Standard Performance Measures
- Automatic Optimisation
- Manual Optimisation

Monitor calibration performance

User Type: MO

Calibration performance can be monitored during calibration in terms of effectiveness, efficiency, robustness, and resources. The following aspects seem to be relevant:- Effectiveness or the chance of finding the global optimum or an acceptable optimum (local or global), in other words the thoroughness of the search- Efficiency, expressed in terms of convergence of the objective function during calibration or the rate at which the final optimum (global or acceptable, but local optimum) can be found; a high rate of convergence will usually be at the expense of the thoroughness of the search (and thus decreasing effectiveness) with the risk of ending up with some local and unacceptable optimum- Robustness, expressed by the degree of satisfaction in meeting other performance criteria as well as the objective function- Resources, expressed in manpower costs, computer costs, etc.- Infrastructural aspects, i.e. requirements to hardware, software neededA record of calibration performance, including values of the parameters, objective function and other performance measures, should be maintained in the model run log (established in Task Test Runs Completed) and attached to the Model Study Journal. If calibration performance is poor, it may be decided whether to go back and select another set of calibration parameters or to go back and select another optimisation method.

Applicable methods:

- Visualisation and Tabulation
- Standard Performance Measures

Calibration measures versus stop criteria

User Type: MO

The activity may involve the execution of postprocessor algorithms to calculate performance criteria for the "parameter optimised" and calibrated model, and to compare these results with the pre-defined goals (stop criteria for calibration). If the pre-defined goals for calibration have all been achieved (or stop criteria formulated as complete date or number of runs has been reached), the calibration inner loop has been completed. If not, it must be decided whether to go back and select another set of calibration parameters or to go back and select another optimisation method.

Applicable methods:

- Visualisation and Tabulation
- Standard Performance Measures

Evaluate parameter estimates

User Type: MO

The optimised parameters should fall within the range specified in the task Model Parameters. Unrealistic model parameters may indicate problems in the conceptual model, low parameter sensitivity or parameter correlation. If inverse optimisation is used, the statistics computed by the inverse algorithm should be examined carefully as much insight in the system behaviour can be learned from here.

Other task aspects

Sensitivities and Pitfalls

1. **Difficulty of Reaching Calibration Criteria** : Not reaching pre-defined calibration requirements (stop criteria); this is often the case if there is not sufficient data or if the model is over-parameterised (too many calibration parameters), both typically indicating that no complex model should be used. User Type: MO
2. **Over-calibration** : Calibration can continue until the output uncertainty is much smaller than the uncertainty in the data (the system observations); this suggests an accuracy which does not reflect actual knowledge of the system and the problem at hand. User Type: MO
3. **Non-coincidence of Observation Point and Model Grid** : Observation points and computational grid nodes are generally not spatially and/or temporally coincident. In the evaluation of the model fit, simulated values should be interpolated in time and space rather than using the closest simulated value. User Type: MO

References

1. Middlemis, H. (2000) Murray-Darling Basin Commission. Groundwater flow modelling guideline. November 2000. Aquaterra Consulting Pty Ltd. Project no. 125. User Type: MO
2. Anderson, M.P. and Woessner, W.W. (1992) Applied groundwater modeling. Simulation of flow and advective transport. Academic Press, San Diego. USA. User Type: MO
3. Hill, M.C. (1998) Methods and guidelines for effective model calibration. With application to: UCODE, a computer code for universal inverse modeling, and MODFLOWP, a computer code for inverse modeling with MODFLOW. U.S. Geological Survey. Water Resources Investigations Report 98-4005. Denver, Colorado. User Type: MO

4.6 All Calibration Stages Completed?

User Type: MO

Definition

To evaluate whether all steps in calibration strategy have been finalised satisfactorily

The task shall monitor the progress in calibration and assure that the a-priori specified steps has been carried out properly. Furthermore the task shall evaluate the overall calibration performance and hence assess the needs for additional steps / repetition of the calibration loop (iteration)

Activities

- Calibration targets vs. simulated values
- Distribution of residuals
- Evaluate pre-defined qualitative criteria
- Other stop criteria
- Need for additional steps?
- Documentation

Calibration targets vs. simulated values

User Type: MO

Visualise difference between observed and simulated state variable used as calibration targets, e.g. heads, fluxes, groundwater ages, and solute concentrations. Evaluate water or mass balances. Select appropriate ways for visualisation, e.g. tables and maps showing distributed values.

Applicable methods:

- Visualisation and Tabulation
- Aggregated Performance Indicators
- Standard Performance Measures

Distribution of residuals

User Type: MO

Analyse the spatial distribution of the residuals. In this activity the spatial and/or temporal distribution of the residual error is presented in the form of maps and graphs comparing observed and simulated value, as well as plots showing the residual distribution in space and time. Ideally, the residuals should be randomly distributed in both time and space. Trends in the residuals can be used to guide further calibration through the adjustment of parameter values and boundary conditions.

Applicable methods:

- Visualisation and Tabulation
- Qualitative Performance Measures

Evaluate pre-defined qualitative criteria

User Type: MO

The activity comprises a critical evaluation of the qualitative criteria defined in the task Specify or Update Calibration and Validation Targets and Criteria. As opposed to the single value criteria (objective function) used to optimised the parameters, the qualitative criteria focuses on the overall model performance, e.g. by the use of aggregated performance criteria. This may also include some additional weighting of which observations/types of observations are most important to match by the model. Normally, a manual examination of graphical outputs from the run is required, eventually by assistance from an in-house model expert (internal QA).

Applicable methods:

- Visualisation and Tabulation
- Aggregated Performance Indicators
- Standard Performance Measures
- Qualitative Performance Measures

Other stop criteria

User Type: MO

In this activity the modeller determines if other criteria not related to calibration performance have been met. These criteria are predefined in the task Define stop criteria and include stopping calibration after using a certain amount of resources, a calendar date or exceeding some maximum number of model runs. If these criteria have not been met, it has to be decided whether to go back and select another set of calibration parameters or to go back and select another optimisation method.

Need for additional steps?

User Type: MO

Have all the steps in the calibration strategy been completed?Analyse results of calibration and make decisions about required additional loop, e.g. Completion of another e.g. steady-state and transient calibration, if required.

Documentation

User Type: MO

Document the steps taken in calibration of the model and discuss changes made in initial parameter values and boundary conditions.

Other task aspects

Sensitivities and Pitfalls

1. **Steady-state Models** : There are a number of pitfalls with steady state calibration. The principle behind steady-state models is that a balanced situation is described, i.e. a situation in which the effects of changes in time can be neglected with regard to the effects to be calculated User Type: MO
2. **Weighting of Observations** : A large number of calibration procedures are based on unweighted criteria. In other words, all measurements are attributed equal importance. This can lead to imbalanced calibration, for example in areas where there are clusters of observations with a great deal of superfluous information User Type: MO
3. **Avoid many Parameters** : A calibration strategy with too many free parameters should be avoided. Therefore, a guiding principle in approaching more complex models, is to construct a model comprising as few free parameter zones as possible User Type: MO
4. **Steady-state Models** : There are a number of pitfalls with steady state calibration. The principle behind steady-state models is that a balanced situation is described, i.e. a situation in which the effects of changes in time can be neglected with regard to the effects to be calculated.It should be noted that there may be several possible steady state situations in ecological systems for a single physical/abiotic situation (e.g. a clear, macrophyte dominated lake or a turbid, algae dominated lake at the same nutrient and hydrological conditions). User Type: MO
5. **Take a Look** : Remember always to check performance by visual inspection! User Type: MO
6. **Boundary Conditions** : In some domains numerous factors usually serve as boundary conditions. They must be correct, because otherwise the starting points for the calculations will be incorrect. In general, boundary conditions should not be incorporated in calibration, but rather handled as alternative conceptual models. However, when specific boundary conditions are unknown, inverse methods can be used to determine them iteratively.In some model applications, a solute transport or biota model or socio-economic model inherits the uncertainties generated by the basic flow model, and add other uncertainties, which may affect the calibration results. Qualitative criteria for the flow model (e.g. gradient or displacement) may be much more critical than the quantitative criteria, but may be difficult to analyse due to lack of data. User Type: MO
7. **Use Multiple Criteria** : It is often difficult to (correctly) interpret calibration performance criteria. Generally a combination of numerical criteria should be used, using only one is dangerous as it may miss important features. User Type: MO
8. **Solute Transport** : Solute transport models inherit the uncertainties associated with the basic flow model, and add other uncertainties, which may affect the calibration results. Qualitative criteria for

the flow model (e.g. gradient or displacement) may be much more critical than the quantitative criteria, but may be difficult to analyse due to lack of data. User Type: MO

9. **Expert Judgement** : For some domains (e.g. economic models) calibration and validation on the basis of expert judgement is often the best method to achieve good model result. However, it is highly recommended that co-operation is sought with specialised agencies and the corporate sector (the branches in question). User Type: MO
10. **Ill-posed Problem/Equifinality** : Calibration is solving the problem: Find the best parameter set (independent data) given the observations of the state variables (dependent data). This problem is most often ill-posed and one consequence is that many different parameter combination may lead to equally well performance criteria. To test if a global minimum is found in the objective function it is advised to start out with different initial parameter combination in the case of inverse optimisation. This may be especially important for parameters with low sensitivities included in the calibration. User Type: MO

4.7 Assess Soundness of Calibration

User Type: MO

Definition

The assessment of the soundness of the calibration is an evaluation of the credibility of the calibrated model based upon professional judgement.

This task is a kind of internal quality assurance, where the modeller steps back from the computer and judge the calibrated model based upon practical experience and sound reasoning. Depending on the quality assurance procedure for the modeller's organisation this task will typically involve a review by the person(s) in the modeller's organisation responsible for internal quality assurance.

Activities

- Reasonable modelling results?
- Reasonable parameter values?
- Speculative or inadequate elements?

Introduction to activities

1. Questions to be asked during the assessment of the soundness of calibration include, but are not limited to the following: Do the results of the calibrated model make sense? Are the ranges of parameters (specified and fitted) in the calibrated model reasonable? Are there elements of the calibrated model that should be identified as being speculative, best guess, or inadequate? User Type: MO

Reasonable modelling results?

User Type: MO

Do the results of the calibrated model make sense? Look carefully at the behaviour of the model when exposed to different stresses. Is the model producing logical and reasonable results for different stresses? Use the intuition of an experienced modeller to identify anything that look strange.

Applicable methods:

- Traces
- Internal Validity

Reasonable parameter values?

User Type: MO

Are the values of parameters (specified and fitted free parameters) in the calibrated model reasonable compared to a priori specified ranges?

Speculative or inadequate elements?

User Type: MO

Are there elements of the calibrated model that should be identified as being speculative, best guess or inadequate?

Other task aspects

Sensitivities and Pitfalls

1. **Many possible Sources of Errors** : This task relies heavily upon the practical experience of the person(s) conducting the soundness assessment.Be aware that malfunctioning of a calibrated model in principle can be caused by several causes: errors in model code, inconsistencies in model set-up, wrong conceptual model, problems due to input data or parameter values etc. User Type: MO
2. **Black Box Models** : The analysis of the adequacy of parameter values may be difficult for models that are not process-oriented and whose parameters have no direct physical meaning. In those cases, the parameter values must be under the sensitivity aspects (is the parameters within a range of values that enables to controlled function to keep its initial role) User Type: MO
3. **Weak Links** : Identification of "weak-links" in the calibrated model will be important during interpretation of the predictive simulations User Type: MO

4.8 Validation

User Type: MO

Definition

Substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with its intended application.

A test to determine whether a calibrated model can be used as a predictive tool, by demonstrating that the calibrated model provides an adequate representation of the physical system. Model simulations are, to the extent possible, compared with independent data to determine whether the model is able to reproduce the past with the required accuracy and whether the model is suitable for use as a predictive tool.

Activities

- Design validation test procedure
- Confirm performance measures
- Process validation data
- Carry out validation test

Design validation test procedure

User Type: MO

The intended use of the model for predictive simulations is analysed and the appropriate test scheme is identified. Examples of considerations in this are whether suitable data exist for calibration/validation (proxy test required?) and whether there are stationarity of conditions in the calibration and prediction periods (differential split-sample test required?). For situations where the most simple test (split-sample) is not adequate, another consideration would be the available resources. Therefore expert evaluations or comparative assessments may some times be preferred instead of the complex proxy basin and differential split-sample tests. The test scheme should be designed taking the particular modelling domain, geographic area and data availability into account. Testing for real time application should use raw real time data records to be as close as possible to real life conditions of model application.

Applicable methods:

- Proxy Basin Test
- Differential Split-sample Test
- Expert Evaluation of Model Performance
- Proxy Basin Differential Split-sample Test
- Comparative Assessment

- Split-sample Test

Confirm performance measures

User Type: MO

Review performance measures decided in the Task Specify or Update Calibration and Validation Targets and Criteria.

Applicable methods:

- Visualisation and Tabulation
- Aggregated Performance Indicators
- Standard Performance Measures
- Extreme-condition Test
- Event Validity
- Statistical Validation
- Qualitative Performance Measures

Process validation data

User Type: MO

Process any additional time-series data necessary to conduct the planned validation strategy, extending the inventory of data prepared in Task Collect and Process Raw Data (Activity Evaluate pre-processed data) to cover any new sub periods of time-series data.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Contouring
- Correlation and Regression
- Differential Split-sample Test
- Surface Fitting
- Aggregation
- Infilling (temporal)
- Zonation

Carry out validation test

User Type: MO

The tests are conducted by running the model, and the objective function values and other performance measures are stored in the model run log (established in Task Test Runs Completed) and attached to the

Model Study Journal. The results are analysed and conclusions are derived with respect to whether the model meets the specified accuracy criteria. On this basis the validation status can be assessed.

Applicable methods:

- Aggregated Performance Indicators
- Visualisation and Tabulation
- Differential Split-sample Test
- Expert Evaluation of Model Performance
- Standard Performance Measures
- Proxy Basin Test
- Event Validity
- Extreme-condition Test
- Proxy Basin Differential Split-sample Test
- Comparative Assessment
- Statistical Validation
- Qualitative Performance Measures
- Split-sample Test

Other task aspects

Sensitivities and Pitfalls

1. **Use of Model if Validation fails or not possible** : It must be realised that the validation tests proposed in this chapter are so demanding that many applications today would fail to meet them. This does not imply that these modelling studies are not useful, only that their output should be recognised to be somewhat more uncertain than is often stated and that they should not make use of the term 'validated model' User Type: MO
2. **Conditional Validation** : A model should only be assumed valid with respect to outputs for which they have explicitly been validated. This means, for instance, that a model which is validated against catchment runoff cannot automatically be assumed valid also for simulation of soil erosion on a hillslope within the catchment, because smaller scale processes may dominate here: it will need validation against hillslope soil erosion data User Type: MO
3. **Thresholds in Ecosystems** : Biotic / ecological changes may occur as unpredictable switches or as a response to a threshold being met. The ability of a model to predict these changes must be investigated. It is important that observed data from extreme events are compared to modelled data (Event Validity). User Type: MO

References

1. Anderson, M.G. and P.D. Bates (Eds.) Model Validation: Perspectives in Hydrological Science. John

Wiley and Sons, 2001.

2. Rykiel, E.J. 1996. Testing Ecological models: the meaning of validation, Ecological Modelling, 90, 229-244. User Type: MO

4.9 Assess Soundness of Validation

User Type: MO

Definition

The assessment of the soundness of the validation is an evaluation of the credibility of the calibrated model based upon professional judgement.

This task is a kind of internal quality assurance, where the modeller steps back from the computer and judge the validated model based upon practical experience and sound reasoning. Depending on the quality assurance procedure for the modeller's organisation this task will typically involve a review by the person(s) in the modeller's organisation responsible for internal quality assurance.

Activities

- Do the results of the validation test(s) make sense?
- Reasonable simulation results?
- Reasonable performance?

Introduction to activities

1. Questions to be asked during the assessment of the soundness of validation include, but are not limited to the following: Do the results of the validation test(s) make sense? Do the validation tests show that the model adequately simulates the response of the system to stresses or conditions significantly different from those represented in the calibrated model?Do the validation test(s) indicate that the ranges of parameters (specified and fitted) in the calibrated model are reasonable?
   User Type: MO

Do the results of the validation test(s) make sense?

User Type: MO

Use intuition as experienced modeller to judge whether the validation test(s) sufficiently support and document the accuracy consistent with the intended application of the model

Reasonable simulation results?

User Type: MO

Do the validation tests show that the model adequately simulates the response of the system to stresses or conditions significantly different from those represented in the calibrated model?

Reasonable performance?

User Type: MO

Do the results of the validation test(s) make sense?The same criteria (quantitative and qualitative) as those used to assess the soundness of calibration results can be used here.

Other task aspects

Sensitivities and Pitfalls

1. **Weak Links** : Identification of "weak-links" in the validated model will be important during interpretation of the predictive simulations User Type: MO
2. **Practical Experience** : This task relies heavily upon the practical experience of the person(s) conducting the soundness analysis. User Type: MO
3. **Sensivity to Parameters** : Different sets of parameters may have implications on model structure (e.g. parameters reflecting seasonal change). Certain trade offs are possible between the selection of parameters reflecting certain cases. User Type: MO

4.10 Uncertainty Analysis of Calibration and Validation

User Type: MO

Definition

Quantification of uncertainty in the calibrated and validated model due to incomplete knowledge of model parameters, input data, boundary conditions and conceptual model. In an uncertainty analysis the combined effects of these uncertainties are taken into account.

This task can be seen as an analysis on top of the calibration and validation tasks. The task is required as a basis for describing the domain of applicability of the model (in Document Model Scope). The task is different from the equivalent task in the next step, Uncertainty Analysis of Simulation, in the way that the present task does not include uncertainty due to management scenarios and decision variables and that it to a less extent deals with model extrapolations beyond the calibration and validation base.

Activities

- Identify Method(s)
- Assess Uncertainty of Input Data
- Assess Uncertainty in Boundary Conditions
- Analyse Uncertainty in Validation Tests
- Analyse Uncertainty for Intended Application

Introduction to activities

1. The activities in this task should end up with an assessment of the uncertainty of the calibrated and validated model for simulation of variables and conditions for which the model is intended to be used in the next step Model Simulation and Evaluation. This involves two stages of analysis:- Firstly to analyse to which extent the performance of the model in the task Validation can be explained by uncertainties in input data, boundary conditions and conceptual model.- Secondly to analyse what the accuracy of the model can be expected to be for output variables and conditions for which the model is intended to be applied in the next step. The activities required for carrying out an uncertainty analysis may inevitably vary depending on the methods that are selected. For instance some of the methods are based on model calculations while others focus on obtaining expert judgements (without modelling). The activities outlined in this task therefore may need to be reconsidered and in some cases even redefined. User Type: MO

Identify Method(s)

User Type: MO

The appropriate method(s) are selected according to requirements specified in the Terms of Reference.

Applicable methods:

- Sensitivity Analysis (PR)
- Error Propagation Equation
- Regression Techniques
- Expert Elicitation
- NUSAP
- Monte Carlo Simulation
- Data Uncertainty (HarmoniRiB)
- Sensitivity Analysis

Assess Uncertainty of Input Data

User Type: MO

This implies two components:- Firstly the input data and parameters that have to be included in the analysis must be identified. Usually it will not be possible to include all data/parameters, therefore the most important ones must be identified. This can be done by sensitivity analysis and often the modellers experience can help in the process as well.- Secondly, the uncertainty ranges and distribution must be assessed. This can be done from a combination of field data, relevant literature and expert judgement.

Applicable methods:

- Data Uncertainty (HarmoniRiB)

Assess Uncertainty in Boundary Conditions

User Type: MO

The boundary conditions for the model are analysed and the uncertainties assessed.

Analyse Uncertainty in Validation Tests

User Type: MO

The uncertainty of the model results for the validation test cases is analysed. This may, depending on the selected method(s), require a large number of simulation runs. These uncertainties are compared with the deviations between model simulation and field data in the validation tests carried out in the task Validation, and conclusions are made whether the deviations in the validation tests may be explained by the uncertainties included in the present analysis. If this is not the case the additional deviations from the validation tests need to be identified and somehow included in the further analysis.

Applicable methods:

- Sensitivity Analysis (PR)
- Regression Techniques
- Monte Carlo Simulation
- Sensitivity Analysis

Analyse Uncertainty for Intended Application

User Type: MO

The uncertainties for the intended types of model application in the step Simulation and Evaluation should be assessed. The types of model application appear from the Terms of Reference and should be specific in terms of for instance which output variables, which type of stress conditions and which scale. This may, depending on the selected method(s), require a large number of simulation runs. Depending on the types of intended applications this may include elements of interpolation and elements of extrapolation compared to the data base available for calibration and validation. The results of this activity will form the basis for the next task Document Model Scope where the capabilities and limitations of the model have to be described.

Applicable methods:

- Sensitivity Analysis (PR)
- Error Propagation Equation
- Regression Techniques
- Expert Elicitation
- NUSAP
- Monte Carlo Simulation
- Sensitivity Analysis

Other task aspects

Sensitivities and Pitfalls

1. **Practical Constraint** : In practice it is not feasible to take all uncertainty aspects into account User Type: MO
2. **Conceptual Model Uncertainty** : Uncertainty of conceptual models are seldom incorporated in uncertainty assessments, but it may in some cases be the most important source of uncertainty User Type: MO
3. **Scales** : Scale issues are very important. Uncertainty cannot be analysed correctly without an explicit understanding and accounting for scale issues User Type: MO
4. **Data Uncertainty** : Uncertainty assessments of basic data in databases usually do not exist as standard information User Type: MO
5. **Select Calibration Parameters** : Results or information obtained in Task Select Calibration Parameters may be useful here. User Type: MO

References

1. In the EU-FP5 project HarmoniRiB, methodologies and tools for assessing uncertainties in various aspects of modelling and decision making is being developed. Results can be found on www.harmonirib.comA useful guide for which methods may be applicable for assessing various sources of uncertainty can be found in the report Refsgaard JC, van der Sluijs JP, Højberg AL and Vanrolleghem P (2005) Harmoni-CA Guidance Un-certainty Analysis. Guidance 1. 46 pp. Downloadable from http://www.harmoni-ca.info User Type: MO

4.11 Scope of Applicability

User Type: MO

Definition

This task describes the circumstances or conditions under which the model has documented predictive capabilities.

Model capabilities and limitations are identified and presented in the context of the utility of the model as a predictive tool given the project objectives defined in the Model Study Plan. This implies that the situations of future model use are compared to the conducted validation tests and that the credibility of using the model for simulation of the planned management scenarios is assessed.

Activities

- Model processes
- Model performance
- Applicability to scenarios
- Uncertainty results
- Describe domain of applicability

Model processes

User Type: MO

Evaluation of the processes represented in the model in relation to future management scenarios. Determine if all of the processes relevant to the future management scenarios (predictive simulations) are adequately represented in the calibrated and validated model.

Model performance

User Type: MO

Evaluation of the quality of calibration and validation in relation to future management scenarios. Determine if the quality of model calibration and validation places any limitations on the predictive capabilities of the model. Are the range of stresses to be imposed in the predictive simulations within the range of stresses under which the model has been calibrated and validated. It should be stated explicitly if the model has not been validated.

Applicability to scenarios

User Type: MO

Assess to what extent the range of conditions or stresses in the scenarios to be investigated (as outlined in

Task Define Objectives and included in the Model Study Plan) are similar to those for which the model was calibrated and validated. Some scenarios could involve significant changes to the model structure (e.g. constructing a reservoir or diversion channel). Calibration and Validation should have confirmed that the basic model processes are represented adequately within the range of the original input conditions, but uncertainties introduced by necessary structural changes to the model should be reviewed:- Are the changes well understood?- Can they be suitably represented in the model?- Have similar changes been reliably modelled before?- Will feedbacks between structural changes and input conditions be properly considered?For example, a river engineering scenario to extend flood plain storage may be modelled with confidence in the Hydrodynamic domain, but it could have more uncertain effects on surface-groundwater interaction, soil-moisture, runoff, evaporation, sensitivity to storm types, water quality, habitats, and a range of socio-economic aspects.

Uncertainty results

User Type: MO

Determine if the results of the uncertainty analysis (calibration and validation) expose any limitations of the model with regard to the future management scenarios (predictive simulations).

Describe domain of applicability

User Type: MO

Summarise the capabilities and limitations of the calibrated and validated model in fulfilling the project objectives as defined in Model Study Plan.

Other task aspects

Sensitivities and Pitfalls

1. **Applications outside Area/field of Validation Tests** : Although it is common practice to do so, care must be taken when predictive simulations are performed using stresses or conditions that are significantly different than those under which the model was calibrated and validated. Therefore it is important to explicitly describe the scope of applicability for which validation tests have documented the predictive capability of the model. If a model is then used outside its documented domain of applicability this should be noted explicitly in the model reporting, because the credibility of the model predictions then will be reduced. User Type: MO
2. **Solute Transport** : Solute transport in the subsurface is highly sensitive to local-scale heterogeneities in e.g. geology or geochemistry, which again may vary greatly over even small scales. The success of a detailed match between simulated and observed plume migration does therefore not imply that the model is equally good in describing future migration. Predictive solute transport at a detailed scale should thus be seen as a model application beyond its domain of applicability. The transport

simulation results must therefore always be interpreted with great care, acknowledging the scale at which information of the system is available compared to the scale at which solute concentrations are extracted from the model simulations. User Type: MO

References

1. J. R. Lund, A.J. Draper et al.: Economic-engineering analysis of Californian water management. Integrated Water Resources Management. The International Association of Hydrological Sciences. IAHS Publ. no. 272, 2001, 191-196. User Type: MO

4.12 Report and Revisit Model Study Plan (Calibration and Validation)

User Type: MO

Definition

Report on model Calibration and Validation, write associated parts of the Project Report, and draft an updated Model Study Plan for the next modelling step.

This task includes:- Reporting the model calibration- Reporting the sensibility analysis of calibration- Reporting the model validation- Reporting the uncertainty analysis of the calibration and validation - Describing the model scope on the basis of documented performance, including its limitations - Updating the project plans for the next modelling step Simulation and Evaluation

Activities

- Report writing
- Draft revised Model Study Plan

Introduction to activities

1. There are two aspects to report on: (1) the tasks already completed (Project Report) and (2) updates to the project plan for the next step in the modelling process (Model Study Plan). User Type: MO

Report writing

User Type: MO

The following parts of the Project Report will be prepared- Model calibration- Model validationThe report should be in a suitable form for the task Review Calibration and Validation and Simulation Plan

Draft revised Model Study Plan

User Type: MO

Prepare in draft an updated version of the Model Study Plan, including an assessment of whether there is a need for additional data to complete the next Step. The project plans for the model step until the next review will be described. In practice this implies that the next part of the Model Study Plan will be upgraded from its current version (agreed under the task Review Model Set-up and Calibration and Validation Plan) using the improved knowledge obtained in the step Calibration and Validation, and providing greater detail on the proposed approach where appropriate. These revised project plans will be discussed during the forthcoming task Review Calibration and Validation and Simulation Plan, and therefore any substantial changes as compared to the earlier version must be emphasised.

Other task aspects

4.13 Review Calibration and Validation and Simulation Plan

User Type: AU,MA,MO,PU,SH

Definition

Review of the tasks carried out within the modelling step Calibration and Validation

This is an important opportunity to check that the project is progressing well towards meeting its objectives. The review will be based on the report on Calibration and Validation (including the assessment of the scope of model applicability), the draft update of the Model Study Plan, the Quality Assurance Plan, and any other information provided by the modeller. The review will be conducted to assess the quality of the work and will form the basis for:- A decision on the formal approval of the work carried out in this modelling step, and- An approval of the detailed plans for Simulation and Evaluation as given in the revised Model Study Plan in the task Report and Revisit Model Study Plan (Calibration and Validation).

Activities

- Review Priorities
- Perform Review
- Stakeholder Feedback
- Manager Responds to Stakeholder Feedback
- Consensus
- Perform Modifications
- Approve Modifications

Review Priorities

User Type: MA

The manager must- Confirm the decisions made in the Quality Assurance Plan, especially on the tasks and activities to be performed and the types of review required (see task Agree on Model Study Plan and Budget)- Identify an independent auditor for the audit/review/appraisal - Decide on the priorities of the tasks (weight factors) to be applied for the model appraisal/peer review/model audit.

Applicable methods:

- Checklist for Reviews/Audits/Appraisals

Perform Review

User Type: AU

Perform review as agreed in Quality Assurance Plan (model Appraisal, Peer Review or Model Audit). In case a scoreboard is used to evaluate the quality of the work the auditor should assess the scores of the individual issues in the domain specific checklists.

Applicable methods:

- Peer Review
- Checklist for Reviews/Audits/Appraisals
- Model Appraisal
- Model Audit

Stakeholder Feedback

User Type: PU,SH

The stakeholders report feedback to the Report on Calibration and Validation. Furthermore, feedback to SIP (see method Stakeholder Involvement Plan) are relevant at this point, with suggestions of adjustments to the SIP for the next phase of the modelling. This could include:- Actions to further support common understanding- Clarification of team roles and responsibilities- Changes in participating stakeholders in working groups- Additional needs for information from general public and stakeholders. Stakeholders and general public should give feedback about needs for adjustment of preferred interaction and communication tools (according to SIP) to be used for the subsequent step until next stakeholder feedback in task 5.7 Review of Simulation and Evaluation (se method Interaction and communication ABC).

Applicable methods:

- Interaction and Communication ABC

Manager Responds to Stakeholder Feedback

User Type: MA

The manager answers comments from stakeholders on Report on Calibration and Validation and decides if changes are needed for the SIP (see method Stakeholder Involvement Plan). The manager reports the comments and answers to both reviewers and modeller. Changes to the SIP are discussed with the modeller and included in the model study plan (SIP chapter). Where evaluation before did take place after the production of the final model, it is imperative to agree with stakeholders and general public about the final simulation scenarios and the needs for uncertainty analysis of the calibrated and validated model. Therefore, the analysis of the stakeholders (see method Stakeholder summary table) should be revisited at this step. Active involvement of stakeholders may be reconsidered. If necessary, the manager adjust selected interaction and communication tools to be used until next review task (see Method Interaction and communication Tools ABC).

Applicable methods:

- Interaction and Communication ABC
- Stakeholder Summary Table

Consensus

User Type: AU,MA,MO

The auditor presents his conclusions and recommendations to the manager and the modeller. Together they decide on the conclusions and necessary actions to be taken as a consequence of the review- Whether the work has been carried out satisfactorily in its present form- Whether specific modifications to the work are required to be carried out by the modeller before proceeding to the next task- Whether unforeseen conditions have arisen so that the work has to return to the task Specify Stages in Calibration Strategy or to previous steps in the modelling process- Whether any proposed changes to the Model Study Plan should be approved

Perform Modifications

User Type: MO

The modeller carries out the agreed modifications and makes the necessary modifications to the reporting in the Project Report.

Approve Modifications

User Type: AU,MA,MO

The modifications made by the modeller are assessed by the manager. The manager may decide to contact the auditor, if required. If the modifications are accepted as satisfactorily the modelling job proceeds with the next task, otherwise the additional modifications have to be agreed upon and the previous activity is repeated.

Other task aspects

Sensitivities and Pitfalls

1. Goodness of Performance/Model Parameters : A major pitfall in this step is that insufficient time is taken, because this step is pressurised by the fact that a final product must be delivered on time.Assessment of whether a model is ‘good’ often does not take place objectively, on the basis of pre-set criteria. In many cases, this assessment depends on the expertise of the modeller. In complicated cases in particular, this expertise is therefore a sensitive factor. In choosing the parameters to be calibrated, the number and the spatial distribution of the degrees of freedom (the model controls) must be geared to the amount of information available for calibration. Calibration of a

model with too many degrees of freedom often results in a distorted picture of the truth. Errors in the model concept can be 'calibrated away' in this manner. In the previous point, there is the paradox that a model seems to fit better when there is less measuring data. In practice however, there is often a tendency to increase the number of parameters to be calibrated, in order to reduce the deviations between the measured and calculated values. There are theoretical concepts ('observability') to determine whether too many degrees of freedom have been defined, but these are not generally used in practice. In a number of cases, estimates are calculated for the reliability of the calibrated parameter values. This is certainly recommendable. For that matter, unknown parameters can also be estimated by means of expert judgement. Default values are usually not adequate, because they apply to a (too) general or a single system. Parameters may not be sensitive to the available observations (not at the locations or times at which there are observations). As a result, the sensitive parameters cannot be adequately calibrated. Comparison of the model results and observations does not always take account of the differences in scale. A point observation is often directly compared with a model value which is representative of a certain volume or a certain time period. Calibration generally does not cover all the sources of uncertainty. Consequently, measuring errors may have a strong effect on a parameter value in small data sets. User Type: AU,MA,MO,PU,SH

2. Computational Time : Before starting the real calculations, there must first be certainty that the model is afforded sufficient run-in time. This may sometimes even be longer than the simulated period. We recommend that the run-in time be estimated on the based of residence time and processing speed, beforehand. User Type: AU,MA,MO,PU,SH
3. Subjectivity : As pointed out by Enserink and Monnikhof (2003) the criteria for judging the quality of participatory process outcomes are inevitably subjective, and the quality of something can therefore only be determined inter-subjectively. The quality of policy outcomes is defined as the extent to which they improve an existing or expected problem situation, thereby meeting the interests of all parties involved as much as possible, and as efficiently as possible. User Type: AU,MA,MO,PU,SH
4. Model Use outside Scope of Applicability : A major pitfall is that the model is used outside of its scope of applicability. This occurs, for example, when the model construction and analyses have taken place using data gained from another water management regime. This usually occurs if the model is used for scenarios which represent the situation of measures yet to be carried out. Remember: a perfect 'history match' is, in itself, no guarantee of a good definition of the system. User Type: AU,MA,MO,PU,SH

References

1. Enserink, B. and Monnikhof, R.A.H. (2003) Information management for public participation in co-designing processes: Evaluation of a Dutch example. User Type: AU,MA,MO,PU,SH

Step 5: Simulation and Evaluation

In this step the calibrated and validated model is used to make simulations to meet the objectives and requirements of the model study. In simulation the validated model is used to gain insight into reality and obtain predictions that can be used by water managers, including how reality might respond to human interventions. Depending on the objectives of the study, these simulations may result in specific results that can be used in subsequent decisions making (e.g. for planning or design purposes) or to improve understanding (e.g. of the hydrological/ecological regime of the study area). In order to arrive at a robust decision it is important to carry out suitable uncertainty assessments of the model predictions. The model results need to be analysed, evaluated, reported and compared to the scope, requirements and objectives originally defined for the modelling study. As with the other steps, the quality of the results needs to be assessed through internal and external reviews. Finally, when all objectives and requirements have been met, the study should be formally closed.

5.1 Set-up Scenarios

User Type: ALL

Definition

Adjust validated model to match the scenario(s), and prepare any additional input data needed to run the model.

Scenarios may involve changes to the model inputs and/or the model structure. The first scenario will often involve the current validated model structure (the 'do nothing' option) but other scenarios may include physical changes to the way the watercourse and its basin behave. This may require significant changes to the structure of the validated model, and thus additional testing of the revised model and re-assessment of its soundness. The task also involves preparing any additional time-series and boundary condition data needed to run the model.

Activities

- Adjust model set-up
- Test runs and soundness
- Process scenario data

Adjust model set-up

User Type: MO

Each of the scenarios outlined in Task Define Objectives (and updated in the Model Study Plan) may involve physical changes to the way the watercourse and its basin behave, and thus require that the validated model be adjusted accordingly. It is not possible to recalibrate or revalidate the adjusted model, because no data exist for the possible future situation characterised by the scenario. The adequacy of the model to simulate such scenario situations should have been assessed in the task Scope of Applicability, and tests to ensure that the behaviour of the adjusted model is sound will be made later in this task.The current activity includes:- Reviewing and adjusting the conceptual model as necessary to match the current scenario- Adjusting as necessary the model set-up dataParticular attention should be paid to the critical effects of boundary conditions and controls within the basin.It should be noted that the model structure may even need adjusting when a scenario involves no apparent structural changes to the watercourse or basin. For example, the available calibration and validation data may not have included extreme high flows, such as might be required in the scenarios. High flows could bring different flow paths or processes (e.g. flood plains, bypassing, backing up, etc) that were not included in the original model, or if they were, could not be validated. The model may have to be adjusted at this stage to improve representation of these features. A scenario may also need to be developed by iteration and trial and error. Put another way, the measure may need to be optimised to meet the project objective. For example, the configuration (size, shape, outlet, etc) of a reservoir may need successive adjustment to provide the necessary holding time to meet a specified water quality improvement objective. In many cases, there is a clear case for carrying out post project appraisal (post audit) for any scenario that is implemented. This involves (a) the collection of system output data to investigate the effectiveness of the measure implemented, but of more generic importance (b) a model validation study to assess model performance and development needs.

Applicable methods:

- Visualisation and Tabulation
- Contouring
- Spatial Interpolation and Integration
- Surface Fitting
- Zonation

Test runs and soundness

User Type: MO

If structural changes have been made to the model, it must be run using test conditions and inputs, and the resulting outputs assessed:- Are the components, parameters, boundary conditions, etc. as intended?- Are there run time errors, warnings or convergence, or execution time problems- Do the outputs (overall mass balances, space and time plots) look reasonable and sensible?)The model may need further adjustment to improve its behaviour.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Aggregation

Process scenario data

User Type: MO

Process any additional data necessary to conduct the model simulations, extending the inventory of data prepared in Task Collect and Process Raw Data (Activity Evaluate pre-processed data) to cover any new sub periods of time-series data. Input files are created in order to represent the future stresses or management scenarios as defined in the Model Study Plan.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Contouring
- Spatial Interpolation and Integration

- Correlation and Regression
- Surface Fitting
- Aggregation
- Infilling (temporal)
- Zonation

Other task aspects

5.2 Simulations

User Type: MO

Definition

Predict system response to possible future scenarios. Real-time runs forecast future system states at a required forecast lead time.

Simulations are made by running the model, adjusted as necessary to represent a future scenario, and imposing expected future stresses and/or management scenarios.

Activities

- Execute simulations
- Store simulations

Execute simulations

User Type: MO

The modeller runs the predictive simulations. This may involve running the model for several periods (events, years) covering a range of conditions. It may also involve some iteration, especially if the scenario involves design decisions. For example, the scenario may specify a river diversion, but appropriate channel dimensions would need to be determined by a sequence of model runs), and the design would then need to be tested under a range of conditions. In cases like these, only simple run details from individual iterations would be recorded in the model run log, but the full results from each simulation period would be recorded for the final run (see next activity). In case of real time applications special care is necessary to handle different scenarios of future meteorological conditions including different arrays of predicted input (e.g. resulting from a limited number of meteorological models, climate based scenarios related to different input variable quantiles, outliers, full sets of ensemble prediction system results, mini-ensembles, ensemble means, control predictions). In case of manual or not fully automated procedures registration of input output relation is essential for all possible time steps within the lead time of the forecast.

Store simulations

User Type: MO

The modeller records the scenario and run details and the derived performance criteria in the model run log (established in Task Test Runs Completed). This is then attached to the Model Study Journal. The model input files and model outputs are also stored in an appropriate data-base structure (possibly as used in Task Process Raw Data and Task Process Model Structure Data), to enable any subsequent assessment, interpretation, or comparison of model results.

Other task aspects

Sensitivities and Pitfalls

1. **Expertise of Forecaster** : Hydrological expertise and judgement of the forecaster may have positive impact on this process based on the knowledge of catchment characteristics and local data and gauge issues. User Type: MO

5.3 Check Simulations

User Type: MO

Definition

Screening the results of the simulations for possible errors. The check of simulations is an inspection of the model results with the objective of exposing extreme or incorrect model output.

Activities

- Identify range of results
- Identify unexpected results
- Identify numerical errors

Introduction to activities

1. The check of simulations includes an inspection and analysis of the model results focusing on identification of unrealistic model results. User Type: MO

Identify range of results

User Type: MO

The modeller inspects the model output and identifies the limits of results defined by high and low values. Values that are considered extremes or outliers are identified.

Identify unexpected results

User Type: MO

The modeller inspects the model output and identifies values that are judged to be improbable.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Aggregation

Identify numerical errors

User Type: MO

The modeller inspects the model output for computational errors, such as mass balance errors, that may be indicative of improper spatial and temporal discretisation, numerical truncation or inappropriate application of a numerical technique.

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Aggregation

Other task aspects

Sensitivities and Pitfalls

1. **Expertise of Modeller** : The overall objective of performing predictive simulations is to provide a quantitative estimate of the unknown. As such, the identification of unexpected results relies heavily upon professional judgement. User Type: MO

5.4 Analyse and Interpret Results

User Type: MO

Definition

Critical examination of the results of the simulations.

The simulation results are interpreted. The significance of the results are related to the modelling objectives as defined in the Model Study Plan. This includes preparation of summary and conclusions for the most important outcomes of the results.

Activities

- Discuss results and draw conclusions
- Objectives achieved?
- Analyse consequences

Introduction to activities

1. The analysis of the results of the simulations includes a description and discussion of the results followed by a conclusion. This includes a check on whether the objectives have been achieved, and an analysis of the consequences of the results for the study. User Type: MO

Discuss results and draw conclusions

User Type: MO

The results of the simulations are summarised using text, figures and tables in order to provide a concise, yet comprehensive description of the relevant results. Furthermore, the results are analysed to extract the key information of particular relevance to the present study. The results are compared on the basis of professional judgement. Any unanticipated results are discussed and supplemented with a possible explanation. The conclusions drawn from the results of the simulations are described in the context of the modelling objectives defined in the Modelling Study Plan.

Objectives achieved?

User Type: MO

Determine whether the simulation runs have met the modelling objectives in the Model Study Plan for this scenario.

Analyse consequences

User Type: MO

Identify the consequences and short-comings of the modelling study. Have the results identified any gaps in knowledge? Is there the need to initiate a follow-up modelling study? Is there the need to collect additional field observations/measurements to support a follow-up modelling study? Is the client satisfied or dissatisfied with the results of the modelling study?

Other task aspects

5.5 Assess Soundness of Simulation

User Type: MO

Definition

A qualitative assessment of the model simulations that takes into account quantitative measures and practical experience.

This task is a kind of internal quality assurance, where the credibility of the simulation results are assessed based on the professional judgement and sound reasoning of the modeller. Depending on the quality assurance procedure for the modeller's organisation this task will typically involve a review by the person(s) in the modeller's organisation responsible for internal quality assurance.

Activities

- Reasonable results?
- Reasonable magnitude?

Introduction to activities

1. This exercise asks the modeller to step back from the computer and judge the results of the model simulations. Based upon practical experience the modeller should especially judge whether the model results make sense and the magnitude of the simulated values are reasonable. User Type: MO

Reasonable results?

User Type: MO

Do the results make sense?

Applicable methods:

- Visualisation and Tabulation
- Mass Balance
- Aggregation

Reasonable magnitude?

User Type: MO

Is the magnitude of the predicted values reasonable?The quality of predictions should be compared to what could be expected in terms of accuracy after validation results.

Applicable methods:

- Visualisation and Tabulation

- Mass Balance
- Aggregation

Other task aspects

Sensitivities and Pitfalls

1. **Practical Experience** : This task relies heavily upon the practical experience of the person(s) performing the soundness analysis. User Type: MO

5.6 Uncertainty Analysis of Simulation

User Type: MO

Definition

Assessment of uncertainty in model results due to incomplete knowledge of model parameters, input data, boundary conditions and conceptual model. Furthermore the uncertainty originating from the decision context (external factors) may be included.

In an uncertainty analysis the combined effects of the various sources of uncertainty are taken into account. The uncertainty analysis of the model simulations is typically carried out to assess the uncertainty of the simulations on the effects of alternative management options. The uncertainties may be expressed in qualitative and/or quantitative terms depending on the nature of the uncertainties, the resources and data available for the modelling study and the selected method of uncertainty analysis.

Activities

- Identify Method(s) to Use
- Assess Uncertainty of the Input Data
- Analyse Uncertainty in Model Boundaries
- Model Structure Uncertainty
- Uncertainty Analysis.
- Analyse Results

Introduction to activities

1. The activities required for carrying out an uncertainty analysis may inevitably vary depending on the methods that are selected. For instance some of the methods are based on model calculations while others focus on obtaining expert judgements (without modelling). The activities outlined in this task therefore may need to be reconsidered and in some cases even redefined. User Type: MO

Identify Method(s) to Use

User Type: MO

The method(s) are selected according to requirements specified in the Terms of Reference.

Applicable methods:

- Sensitivity Analysis (PR)
- Error Propagation Equation
- Regression Techniques

- State Space Techniques
- Scenario Analysis
- Expert Elicitation
- NUSAP
- Analytical Solutions of Stochastic PDEs
- Monte Carlo Simulation
- Data Uncertainty (HarmoniRiB)
- Sensitivity Analysis

Assess Uncertainty of the Input Data

User Type: MO

This implies two components:- Firstly the input data and parameters that have to be included in the analysis must be identified. Usually it will not be possible to include all data/parameters and the most important ones must be identified. This can be done by sensitivity analysis and often the modellers experience can help in the process as well.- Secondly, the uncertainty ranges and distribution must be assessed. This can be done from a combination of field data, relevant literature and expert judgement.

Applicable methods:

- Data Uncertainty (HarmoniRiB)

Analyse Uncertainty in Model Boundaries

User Type: MO

The boundary conditions for the model are analysed and the uncertainties assessed.

Model Structure Uncertainty

User Type: MO

The uncertainty due to model structure error is recognised as often being the most dominant source of uncertainty in model predictions. This uncertainty is difficult to assess. One method to use is to adopt alternative conceptual models and, using a scenario approach, study the importance of different model structures on the model predictions.

Applicable methods:

- Expert Elicitation
- NUSAP
- Monte Carlo Simulation
- Sensitivity Analysis

Uncertainty Analysis.

User Type: MO

Perform the simulation runs.

Applicable methods:

- Sensitivity Analysis (PR)
- Regression Techniques
- State Space Techniques
- Scenario Analysis
- Analytical Solutions of Stochastic PDEs
- Monte Carlo Simulation
- Sensitivity Analysis

Analyse Results

User Type: MO

This activity consists of the following two elements:- Analyse the soundness of the uncertainty results. If some of the results are surprisingly different from the anticipated results, these results will be checked with a view to identify possible errors and flaws.- Analyse whether the assessed uncertainties complies with the requirements specified in the Terms of Reference. Possible areas of non-compliance are noted.

Other task aspects

Sensitivities and Pitfalls

1. **Model Conceptual Uncertainty** : Uncertainty of conceptual models are seldom incorporated in uncertainty assessments, but it may in some cases be the most important source of uncertainty. User Type: MO
2. **Uncertainty of Forecasts** : In real-time conditions, predictive uncertainty may help manager to make decisions. However, giving predictive uncertainty may be difficult in some cases without heavy computations. Therefore the predictive uncertainty may be based on some uncertainty measures assessed during previous tests of calibration and validation. User Type: MO
3. **Scales** : Scale issues are very important. Uncertainty cannot be analysed correctly without an explicit understanding and accounting for scale issues. User Type: MO
4. **Data Uncertainty** : Uncertainty assessments of basic data in databases usually do not exist as standard information. User Type: MO
5. **Uncertainty often not accounted for** : In practice it is not feasible to take all uncertainty aspects into account. Two aspects that are not included in the above methodology are: (a) uncertainty on the future scenarios to be predicted (e.g. involving impacts of future human activities) and (b) ignorance,

i.e. the fact that there may always be aspects that we do not know and even may not be able to imagine User Type: MO

6. **Forecasting Uncertainty** : In real time applications interaction by the forecaster may improve model performance at certain instances by way of accounting model idiosyncrasies and adopting results to customer or partner needs. In the same time this intervention enters additional element of uncertainty to the system. User Type: MO
7. **Reliability of Uncertainty Results** : Take account of the uncertainty bandwidth when interpreting the results. Check, for example, whether a distinction can still be made between the results of various scenarios. When presentation packages are used, units or flow directions have been known to become switched. The absolute values may well be correct, but in the wrong direction. User Type: MO
8. **Be Aware when Extrapolating beyond Calibration Base** : Parameters/ input data most sensitive in the calibration phase may not necessarily be the parameters /input data most sensitive in the prediction phase. This may especially be true when model predictions concerns state variables different from those use in the calibration. User Type: MO

References

1. In the EU-FP5 project HarmoniRiB, methodologies and tools for assessing uncertainties in various aspects of modelling and decision making is being developed. Results can be found on www.harmonirib.comA useful guide for which methods may be applicable for assessing various sources of uncertainty can be found in the report Refsgaard JC, van der Sluijs JP, Højberg AL and Vanrolleghem P (2005) Harmoni-CA Guidance Un-certainty Analysis. Guidance 1. 46 pp. Downloadable from http://www.harmoni-ca.info User Type: MO

5.7 All Scenarios Completed?

User Type: ALL

Definition

Decide whether another scenario needs to be analysed. If not, compare results from those already analysed.

Activities

- Scenarios and objectives
- Compare scenarios

Scenarios and objectives

User Type: MO

A number of questions should be addressed:- Were any problems identified with the current scenario, and could they be resolved by adjusting the model or the measure being assessed?- Have all the scenarios given in the Model Study Plan been run?- Should additional versions of a scenario be run (e.g. would a small change to a measure help meet the study objectives)?

Compare scenarios

User Type: MO

When all scenarios have been satisfactorily addressed, the relative merits (costs, timeliness, environmental impact, etc) of any intervention measures should be compared. This could result in defining a ranked list of options to be presented to the water manager.

Other task aspects

5.8 Reporting of Simulation and Evaluation

User Type: MO

Definition

Reporting of the results from the modelling step Simulation and Evaluation

This involves preparation of the parts of the Project Report covering model predictions for the required scenarios, so that a draft final report on the whole model study will be completed (the previous parts having been completed in the reports of previous modelling steps). This task additionally includes preparation of the executive summary for the whole model study.

Activities

- Report writing

Introduction to activities

1. The reporting consists of two parts:- Reporting of results from the modelling step Simulation and Evaluation- Finalising the overall Project Report into a Draft Final Report, including preparation of an Executive Summary User Type: MO
2. Transmission of forecast results with associated uncertainty to client/users or general dissemination publication of those. Reporting of forecast performance. User Type: MO

Report writing

User Type: MO

The Project Report will be upgraded to a Draft Report. This includes:- Preparation of the part of the report on Model simulation, including uncertainty aspects- Preparation of Executive Summary- Layout and editing of report from previous steps.

Other task aspects

Sensitivities and Pitfalls

1. **Communication to Non-Modellers** : Reporting must take place in the 'language' of the client and stakeholders. It is important that a correct balance is found between the (technical) details and the degree of usability for the client. In practice, reports are often incomplete, so that the modelling process is not reproducible on the basis of the report.An essential pitfall often encountered by both the client and the modeller is that the transfer of knowledge often does not exceed beyond the completion of the report. Consequently, the information provided by the modeller may be incorrectly

applied. While this, in theory, is prevented when a report is good, in practice it becomes apparent that a written report alone is hardly ever sufficient to provide a client with exactly the information required. Personal contact between the modeller and client is essential. It is the responsibility of the modeller to monitor whether the information provided by him has been used in the correct manner, insofar as he has any influence in this matter. User Type: MO

5.9 Review of Simulation and Evaluation

User Type: AU,MA,MO,PU,SH

Definition

Review of the tasks carried out within the modelling step Simulation and Evaluation

The work will be reviewed on the basis of reporting and possible other information provided by the modeller. The review will be conducted with the aim of assessing the quality of the work and will provide the basis for a decision on the formal approval of the work carried out in this modelling step and hence a formal approval of all project work required before the closure of model study.

Activities

- Review Priorities
- Perform Review
- Stakeholder Feedback
- Manager Responds to Stakeholder Feedback
- Consensus
- Perform Modifications
- Approve Modifications

Review Priorities

User Type: MA

The manager must- Confirm the decision made in the Quality Assurance Plan under task Agree on Model Study Plan and Budget- Identify an independent auditor for the audit/review/appraisal - Decide on the priorities of the tasks (weight factors) to be applied for the model appraisal/peer review/model audit.

Applicable methods:

- Checklist for Reviews/Audits/Appraisals

Perform Review

User Type: AU

Perform review as agreed in Quality Assurance Plan (model Appraisal, Peer Review or Model Audit). In case a scoreboard is used to evaluate the quality of the work the auditor should assess the scores of the individual issues in the domain specific checklists.

Applicable methods:

- Peer Review

- Checklist for Reviews/Audits/Appraisals
- Model Appraisal
- Model Audit

Stakeholder Feedback

User Type: PU,SH

The stakeholders report feedback to the Report on Simulation and Evaluation. Furthermore, feedback to SIP (see method Stakeholder Involvement Plan) are relevant at this point, with suggestions of adjustments to the SIP for the next phase of the modelling. This could include:- Actions to further support common understanding- Clarification of team roles and responsibilities- Changes in participating stakeholders in working groups- Additional needs for information from general public and stakeholders(see method Interaction and Communication ABC)

Applicable methods:

- Interaction and Communication ABC

Manager Responds to Stakeholder Feedback

User Type: MA

The manager answers comments from stakeholders on Report on Simulation and Evaluation and decides if changes are needed for the SIP (see method Stakeholder Involvement Plan). The manager reports the comments and answers to both reviewers and modeller. Changes to the SIP are discussed with the modeller and included in the model study plan (SIP chapter).

Applicable methods:

- Interaction and Communication ABC

Consensus

User Type: AU,MA,MO

The auditor presents his conclusions and recommendations for the manager and the modeller and decisions are made with respect to:- Whether the work has been carried out satisfactorily in its present form;- Whether specific modifications to the work is required to be carried out by the modeller before proceeding to the next task; or- Whether unforeseen conditions have arisen so that the work has to return to the task simulations or to previous steps in the modelling process.

Perform Modifications

User Type: MO

The modeller carries out the required modifications and makes the necessary modifications to the reporting in the Project Report.

Approve Modifications

User Type: AU,MA,MO

The modifications made by the modeller are assessed by the manager. The manager may decide to contact the auditor, if required. If the modifications are accepted as satisfactorily the modelling job proceeds with the next task, otherwise the additional modifications have to be agreed upon and the previous activity is repeated.

Other task aspects

5.10 Need for Post Audit

User Type: MA,PU,SH

Definition

A post audit (or a post project appraisal) is a review of the modelling study carried out after some time when new information is available.

The new information that may justify a post audit could be new monitoring data which make it possible to assess the accuracy of the model simulations made during the original study. This could then be seen as a validation test based on independent data.

Activities

- Decide on Post Audit

Decide on Post Audit

User Type: MA,PU,SH

The need to prepare a so-called post audit or a post project appraisal should be decided. Such post audit will typically be carried out when new information is available, e.g. after implementation of a project and/or new monitoring data. A post audit will typically be an independent modelling study with separate contractual arrangements. Although some tasks may be bypassed it will have to go through the same five steps as the original study.

Other task aspects

5.11 Model Study Closure

User Type: MA,MO

Definition

Formal completion of the modelling job

This involves practical and contractual arrangements following the approval of the final Project Report such as archiving, transfer of project results to the manager and settlement of payments. Furthermore, service in a possible maintenance or warranty period may be included.

Activities

- Archiving of results
- Transfer of results
- Settlement of payments etc
- Service in maintenance/warranty period

Introduction to activities

1. The activities to be carried out in connection with the formal closure should be described in the Model Study Plan and the contract. This may e.g. include archiving of results, transfer of results from modeller to manager, settlement of remaining payments, and service in maintenance/warranty period. User Type: MA,MO

Archiving of results

User Type: MO

The material from the modelling study is archived. The archiving should as a minimum include all material required to reproduce all modelling runs at a later point in time.

Transfer of results

User Type: MA,MO

This may e.g. involve some of the following elements, according to previous agreements:- Provision of Final Project Report;- Transfer of digital version of final model to manager;- Provision of any other project output-Staff training in case a model software is delivered.

Settlement of payments etc

User Type: MA,MO

Any remaining payments, guarantees, letters of completion or similar have to be finally settled according to previous agreements.

Service in maintenance/warranty period

User Type: MO

If a maintenance/warranty period with backup service from the modeller to the manager is included in the agreement between the parties, the modeller has to provide such service. This may have one of the following forms:- Maintenance and support for a given period. This may for instance be relevant if the modelling job is completed with a transfer of a model to the manager's organisation for subsequent operational application.- Warranty in terms of support to rectify unforeseen, gross errors in model results or in a model installed at the manager's organisation.

Other task aspects