Appendix B: The Knowledge Base in MoST - Methods

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

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http://www.harmoniqua.org

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Actors grouping

The basis of the planning is the grouping of the actors after involvement. At this inventory these are grouped into four main categories: - Co-operators: In reference to HarmoniQuA everybody involved in exchange of information. Means: project group meetings, lists of action points, working documents etc. all registered into HarmoniQuA monitoring tool.- Co-thinkers: Actors who can, at any moment in the process, be consulted or who contribute in an active way (i.e. consultation). Means: interviews and workshops, newsletter, comment rounds and by access to monitoring tool as User: 'Stakeholder'- Co-knowers: Actors who need to be well-informed of the project (i.e. information supply). Means: a general brochure, internet site, information meeting and by access to monitoring tool as User: 'General public' with easy and effective information. Giving general public access to GIS maps and knowledge base in a navigable, understandable and by help of games way improve overall communication and also allow valuable responses from citizens and undefined stakeholders.- Deciders: In the case the responsible water manager but also competent authorities (and their advisors), that can take decisions at critical moments. Means: review reports (revisiting model study plan) and presentations. Appoint one member of the project team explicitly responsible for the communication. Consider regrouping of actors at every review step in the process. Make use of as much as possible existing communication channels and means build into HarmoniQuA. Make sure that the project team is reachable.

References:

EC (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document no. 8. Public Participation in relation to the Water Framework Directive. Produced by working group 2.9 Public Participation. Luxembourg 2003. 214 pp.
http://forum.europa.eu.int/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents/0publishedsguidancesdocu&vm=detailed&sb=Title

Aggregated Performance Indicators

When dealing with a number of different calibration criteria (e.g. R2, RMS and mass balance) and a high number of selected observation points, it may be helpful to use aggregated score systems, in order to support the overview of the model performance. Each performance criteria is for instance classified into 5 classes, and 1-5 points are given according to this classification for each observation point or layer in the model. Finally, an aggregated score is calculated for the entire model or e.g. all gauging stations.

Aggregation

Data at short space and time intervals may be required as input to a model, but the extent of data involved can make it difficult to identify simple relationships. The spatial and temporal aggregation of data or model outputs (point to zone, subarea or catchment average; instantaneous to hourly, daily, monthly or annual totals), combined with visualisation or tabulation, can identify gross errors in model inputs or set-up (e.g. bad connectivity between zones). In particular, event totals of riverflow and areal rainfall should be evaluated, and the ratio between them (the Runoff Factor) investigated. In general, lower Runoff Factors are likely in summer and in dry periods when soil moisture status is low, but the effects of intense summer storms, frozen ground in winter, and snowmelt in spring could cause significant variations in any trend. Aggregation over time is usually accomplished using the Trapezoidal rule (assuming linear variation between timesteps), but aggregation in space can adopt various approaches, including zonation (e.g. Thiessen Polygons), contouring, and surface fitting, described separately. Note also that aggregation lies at the core of the Mass Balance check also described separately.

Analytical Solutions of Stochastic PDEs

The stochastic partial differential equations are simplified and solved analytically. This is often done by elegant mathematical perturbation techniques and is proven to be very useful in obtaining general insight into fundamental research problems. However, this method puts significant limitations on the range of data input, the size of the problem, the boundary conditions and other aspects. For instance, it is generally not possible for models where several equations are coupled. Thus it has a rather limited practical applicability.

References:

Dagan, G. (1986) Statistical theory on groundwater flow and transport: pore to laboratory, laboratory to formation, and formation to regional scale. Water Resources Research, 15, 5-13.

Gelhar, L.W. (1986) Stochastic subsurface hydrology. From theory to applications. Water Resources Research, 22(9), 135-145

Examples:

Jensen, K.H. and A. Mantoglou (1992) Application of stochastic unsaturated flow theory, numerical simulations and comparison to field observations. Water Resources Research, 28(1), 269-284.

Automatic Optimisation

An alternative for manual optimisation is automatic optimisation, whereby the minimum of the objective function is sought systematically in an iterative process. The modeller therefore no longer needs to adjust the parameter values during the process. This actually makes the optimisation process a parameter estimation process, a search in the parameter space (searching in an n dimensional space, whereby n is the number of parameters to be estimated). Working from a certain state of affairs (a certain fit between the model and field situation, or from a certain value of the objective function at that point in time), the modeller can determine whether the situation can be improved. Often a certain mathematical technique is applied to determine the direction in which the parameter values must be adjusted, and how large that adjustment must be. Calculation of the model continues using the new parameter values, the objective value is re-assessed. The modeller checks whether the value of the objective function meets the pre-set criteria (i.e. is it small enough). If this is indeed the case, the process can be halted, if not, then one or more new vectors will be chosen again. Etc.Many automatic methods allow the total calibration process to be divided into pieces that can be allocated to separate computer processors (i.e. simple parallel computing). Several Grid solutions, using PC's linked by the internet for complex calculations, have been or are being developed and may change the logistics of computation jobs in the near future. A main advantage of automatic optimisation is that many methods also generate information on the reliability (uncertainty) of the model. This information can be used in the uncertainty analysis. The inverse methods can be classified in two groups:- those that use only function evaluations (i.e. changing parameters, running the model and calculating the objective function); these are sometimes called stochastic methods- those that require evaluations of the derivatives of the functions (i.e. of the model); these are sometimes called deterministic methods. This has several complicating consequences. In many model these derivatives are not known at certain points in time. It has also to be mentioned here that some methods require a storage capacity of order N (the number of parameters) and others of order N2. This is extremely important in cases of a complex model (many observed variables, many steps in time and many parameters to estimate). In practice, the modeller will often be limited to the built-in calibration options of a software tool and will choose one of those. When more than one method has been included, it may be worth while to compare the methods.

References:

Hendriks Th.H.B. & P. Van Beek, 1991. Optimaliseringstechnieken, Bohn Stafleu Van Loghum BV, Houten, Zaventem, 348 pp.

Hendrix E.M.T., 1998. Global optimization at work, WAU, Wageningen, 248 pp.Press W.H., B.P.

Flannery, S.A. Teukolsky & W.T. Vetterling, 1992. Numerical recipes: the art of scientific computing, Cambridge University Press, Cambridge, 818 pp.

BMW Toolbox

In the project "Benchmark Models for the Water Framework Directive" a toolbox has been developed to support the selection of appropriate model codes in various fields of water management. The Toolbox includes an inventory of available codes and a set of criteria to guide a user in selecting an appropriate code.

References:

http://www.rbm-toolbox.net/bmw/index.php

Checklist for Reviews/Audits/Appraisals

A general scoreboard is available within the KB to give priorities of which elements of the study should be given highest priority in the review and to monitor and weight the performance scores for these elements. The example-questions below, where the numbers in white cells should be filled out by the water manager and the evaluator, may serve as inspiration.

Modelling step / Issue	**Weight (to be provided by the manager beforehand)**	**Max score**	**Evaluation - actual score**	**Weighted proposal score**	**Score guidance**

		Step	**Within step**			**(Max = 100%)**	**Score 0**	**Score 1**	**Score 3**	**Score 5**
	Step 1: Model Study Plan	5				3,5				
1.1	Are the project objectives clearly defined?		10	5	3	0,3	Missing	Deficient	Adequate	Very Good
1.2	Are the modelling approach and complexity clearly defined?		15	5	4	0,6	Missing	Deficient	Adequate	Very Good
1,3	Are the accuracy criteria clearly defined?		5	5	1	0,1	Missing	Deficient	Adequate	Very Good
1.4	Are the sources of uncertainty clearly defined and incorporated into the modelling approach?		10	5	1	0,1	Missing	Deficient	Adequate	Very Good
1.5	Are the roles of stakeholders and public clearly defined and their views taken into account?		10	5	3	0,3	Missing	Deficient	Adequate	Very Good
1.6	Are requirements for archiving datasets, model setup and results clearly defined?		5	5	5	0,3	Missing	Deficient	Adequate	Very Good
1.7	Are the final products from the modelling study clearly defined?		5	5	4	0,2	Missing	Deficient	Adequate	Very Good
1.8	Are the resources available for the project enough to achieve the objectives within the available time?		10	5	5	0,5	Missing	Deficient	Adequate	Very Good
1.9	Have appropriately qualified staff been selected to supervise and run the modelling work?		30	5	4	1,2	Missing	Deficient	Adequate	Very Good
	Step 2: Data and Conceptualisation	40				31,1				
2.1	Are the relevant processes in the system adequately identified?		10	5	3	2,4	Missing	Deficient	Adequate	Very Good
2.2	Are the data necessary to fulfil the objectives clearly identified?		5	5	5	2,0	Missing	Deficient	Adequate	Very Good
2.3	Have the raw data been retrieved, processed and analysed?		5	5	4	1,6	Missing	Deficient	Adequate	Very Good
2.4	Has an assessment been made of whether the available data are sufficient for the job?		5	3	3	2,0	No		Yes	
2.5	Does the conceptual model address all relevant processes and their interdependencies?		15	5	4	4,8	Missing	Deficient	Adequate	Very Good
2.6	Is the conceptual model (spatial and temporal scales, domain, boundary conditions,...) adequately defined and are the assumptions of the model clearly stated?		5	5	4	1,6	Missing	Deficient	Adequate	Very Good
2.7	Is there a parameterisation scheme so that it is clear which model parameters will be assessed from broad observed properties (and how) and which parameters will be assessed through calibration?		10	5	3	2,4	Missing	Deficient	Adequate	Very Good
2.8	Has the need for alternative conceptual models been assessed?		10	3	0	0,0	No		Yes	
2.9	Has an internal quality assurance of the conceptual model been made - and does the analysis make sense? Has this or a similar conceptual model been successfully applied in previous studies?		10	5	2	1,6	Missing	Deficient	Adequate	Very Good
2.10	Is the conceptual model consistent with the project objectives and the required model complexity?		5	3	3	2,0	No		Yes	
2.11	Is the selected model code consistent with the conceptual model?		10	3	5	6,7	No		Yes	
2.12	Is the report well structured		5	3	3	2,0	No		Yes	

	(according to the standard Project Report)?									
2.13	Is the report well written (consider quality of language, arguments, figures, tables etc.)?		5	3	3	2,0	No		Yes	
	Step 3: Model Set-up	15				13,7				
3.1	Is the model well constructed (in terms of space, time step, initial and boundary conditions and domain coupling)?		30	5	4	3,6	Poor	Deficient	Adequate	Very Good
3.2	Have the test model runs been carried out successfully?		20	3	3	3,0	No		Yes	
3.3	Are the calibration and validation targets and criteria defined adequately?		20	5	3	1,8	Missing	Deficient	Adequate	Very Good
3.4	Is the report well structured (according to the standard Project Report)?		15	3	4	3,0	No		Yes	
3.5	Is the report well written (consider quality of language, arguments, figures, tables etc.)?		15	3	3	2,3	No		Yes	
	Step 4: Calibration and Validation	30				16,8				
4.1	Has the calibration strategy been described well?		5	5	3	0,9	Missing	Deficient	Adequate	Very Good
4.2	Is the selected parameter estimation method adequate?		5	5	5	1,5	Poor	Deficient	Adequate	Very Good
4.3	Have calibration parameters been robustly selected? (e.g. through a sensitivity analysis)		5	5	4	1,2	Missing	Deficient	Adequate	Very Good
4.4	Is the calibration well performed (are performance criteria met)?		5	5	4	1,2	Missing	Deficient	Adequate	Very Good
4.5	Has an internal quality assurance of the calibration results been made?		5	5	2	0,6	Missing	Deficient	Adequate	Very Good
4.6	Is the validation strategy adequate for the project?		10	5	2	1,2	Missing	Deficient	Adequate	Very Good
4.7	Is the model validation well performed (are performance criteria met)?		20	5	2	2,4	Missing	Deficient	Adequate	Very Good
4.8	Has an internal quality assurance of the validation results been made?		5	5	2	0,6	Missing	Deficient	Adequate	Very Good
4.9	Has an uncertainty analysis been made of the calibrated and validated model?		20	5	3	3,6	Missing	Deficient	Adequate	Very Good
4.10	Has the scope of model applicability been well described, and have the limitations in documented performance been suitably emphasised?		10	5	1	0,6	Missing	Deficient	Adequate	Very Good
4.11	Is the report well structured (according to the standard Project Report)?		5	3	3	1,5	No		Yes	
4.12	Is the report well written (consider quality of language, arguments, figures, tables etc.)?		5	3	3	1,5	No		Yes	
	Step 5: Simulation and Evaluation	10				7,7				
5.1	Are the scenarios used to set-up the simulations adequate to achieve the project's objectives?		15	5	5	1,5	Missing	Deficient	Adequate	Very Good
5.2	Have the model runs been carried out successfully?		10	3	3	1,0	No		Yes	
5.3	Are the model results realistic?		10	3	2	0,7	No		Yes	
5.4	Have the simulations been checked for error and are the computational errors (e.g. mass balance errors) acceptable?		10	3	3	1,0	No		Yes	
5.5	Are model outputs adequately analysed and presented in an		10	3	3	1,0	No		Yes	

	easily understandable form to support the scenario analysis?									
5.6	Have uncertainty analysis for the simulation results been made?		20	5	1	0,4	Missing	Deficient	Adequate	Very Good
5.7	Are the project objectives fulfilled?		10	5	3	0,6	Missing	Deficient	Adequate	Very Good
5.8	Is the report well structured (according to the standard Project Report)?		5	3	3	0,5	No		Yes	
5.9	Is the report well written (consider quality of language, arguments, figures, tables etc.)?		10	3	3	1,0	No		Yes	
Total		***100***				***72,7***				

Notes:

(1) coloured cells to be protected

(2) non-coloured cells: to be filled in by manager or the auditor

(3) A lot of checks have to be made (sum = 100%, actual score not larger than max xcore, etc.)

Combined Methods

These methods use global oriented algorithms (i.e. CRS, PRS, multistart) for a global step in the calibration and other algorithms (simplex, direction-set methods) for a local search at interesting points found by the 'global' method. In practice this combined method is rather successful. Examples are given by Duan et al. (1992), Sorooshian et al. (1993) and Gan and Biftu (1996). The Shuffled Complex Evolution (SCE-UA) method (Duan et al, 1992, 1993) can be likened to a combination method, using concepts similar to the Simulated Annealing and Simplex to make populations of parameter sets evolve toward an optimum.

References:

Duan, Q., Sorooshian, S. and Gupta, V. K. (1992). Effective and efficient global optimization for conceptual rainfall-runoff models. Water Resources Research, 28(4), 1015-1031.

Duan, Q., Gupta, V. K. and Sorooshian, S. (1993). Shuffled Complex Evolution approach for effective and efficient global minimization. Journal of Optimization Theory and Applications, 76(3), 163-168.

Gan, T. Y. and 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.

Sorooshian, S., Duan, Q. and Gupta, V. K. (1993). Calibration of rainfall-runoff models: application of global optimization to the Sacramento soil moisture accounting model. Water Resources Research, 29(3), 1185-1194.

Comparative Assessment

Model performances should be assessed comparatively to another model. This other model can either be a model of the same complexity as the model used in the present study or a simpler model. By using two (or more) different model structures to simulate the type of situations for which the model is intended to be used an assessment of the accuracy of the model can be made. This is not as strong a test as when a model can be tested directly against relevant field data, but if such data are not available it may be very useful. If a simple model is used, this can serve as a reference or baseline in terms of model performance. Similarly, relative performance criteria can be built to assess comparative performances. This is what is implicitly done when using the Nash-Sutcliffe criterion: one compares model performances to the performance of a simple model that would give at each time step the mean observed flow. The choice of a baseline model may depend on model application. For example, the baseline model in a flood forecasting context would be to give as forecast streamflow the streamflow observed on the moment of issuing the forecast.

References:

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

Examples:

Ågren, G.I., McMurtie, R.E., Parton, W.J., Pastor, J. and Shugart, H.H. 1991. State-of-the art models of production-decomposition linkages in conifer and grassland ecosystems. Ecol. Appl., 1: 118-138.

Cess, R.D., Potter, G.L., Blanchet, J.P., Boer, G.J., Del Genio, A.D., Deque, M., Dymnikov, V., Galin, V., Gates, W.L., Ghan, S.J., Kiehl, J.T., Lacis, A.A., Le Treut, H., Li, Z-X., Liang, X-Z., McAvaney, B.J. Meleshko, V.P., Mitchell, J.F.B., Morcrette, J-J., Randall, D.A., Rikus, L., Roeckner, E., Royer, J.F., Schlese, U., Sheinin, D.A., Slingo, A., Sokolov, A.P., Taylor, K.E., Washington, W.M., Wetherald, R.T., Yagai, I. and Zhang, M.H., 1990. Intercomparison and interpretation of climate feedback processes in 19 atmospheric general circulation models. J. Geophys. Res., 95: 16601-16615.

Contouring

Contouring may be used both to interpolate data at locations that are new or where data is missing, and to allow the integration of volume under the surface. Manual contouring may be used, especially where data are sparse and/or expert factors need to be taken into account. Examples include drawing isohytes (contours of rainfall depth) using gauged values and topography (altitude, aspect, rain shadow, etc); or defining stratigraphic surfaces based on limited borehole data in areas subject to extensive faulting and folding. However, automatic GIS based procedures are available, involving the development of:- a grid or triangular irregular network (TIN) to represent the point data as a surface- interpolation within the network to define contours and polygons around specified ranges of data valueVarious options are usually available for developing the network, as described separately under the surface fitting method.

Controlled Random Search

The method of Controlled Random Search resembles Pure Random Search, except for the way new parameter vectors are drawn (Price, 1977). With this approach the results of the calibration procedure consists of a set of parameter vectors (each with values for all uncertain parameters). These a postiori parameter distributions (with covariance between parameters) can be used to calculate model outcome uncertainty, i.e. a complete set of model outcomes for each parameter set (Klepper et al., 1991, Klepper and Rouse, 1991). The latter results can also be used (with new object system observations) in a model validation, which is the final step in the modelling procedure before a model might be used for prediction. Controlled Random Search (CRS) is a variant on Pure Random Search (PRS), but its convergence is better, which is caused by the way new parameter vectors are generated (Price, 1977). From a sample of n+1 parameter vectors, n are used to calculate a centroid. In the original CRS, the last vector will be reflected to generate a new vector. The new vector replaces the worst of the stored parameter vectors, if the distance between model results and observations of the new vector is smaller than of the worst vector in storage. The method minimizes therefore some distance, the Lack of Fit. Using CRS to calibrate a model with large initial uncertainty in the output compared to any uncertainty in the observations will normally be quite successful, but it reduces model uncertainty often to much smaller bands than those of the observations. To stop the calibration at any reasonable point, some constraint is required. This mechanism should control the calibration and lead to an optimal fit between uncertain model results and uncertain observations.

References:

Klepper O. & D.I. Rouse, 1991. A procedure to reduce parameter uncertainty for complex models by comparison with real system output illustrated on a potato growth model. Agricultural Systems, 36: 375-395.

Klepper O., H. Scholten & J.P.G. Van de Kamer, 1991. Prediction uncertainty in an ecological model of the Oosterschelde estuary, S.W. Netherlands. Journal of Forecasting, 10: 191-209.

Price W.L., 1977. A controlled random search procedure for global optimisation. The Computer Journal, 20: 367-370.

Correlation and Regression

Correlation and Regression are related statistical methods available in most spreadsheet packages to derive the slope, intercept, error and overall scatter in a straight line relationship between two variables (or functions thereof). They are often used as an extension of visualisation, for example to find best-fit equations for rating curves, or to define relationships between time-series plots at nearby sites. The procedures can be extended:- To multi- variables, e.g. relating flow at A to rainfall and/or flow at B, C, D, etc- To auto-correlation/regression, i.e. relating flow at time t to flow at a previous timestep t-1. In both cases, the relationships may be used to infill missing data, while in the latter case, auto-regression of the log function of flow against time is often used to assess hydrograph recession rates.

References:

Holder R L (1985) Multiple Regression in Hydrology, Institute of Hydrology, Wallingford, UK.WMO (1994) Guide to Hydrological Practices

Cost assessment methodologies

According to the cost recovery principle of the EU Water Framework Directive (WFD)there are different types of cost assessments by using the categories 'financial costs', 'environmental costs' and 'resource costs'. The first category covers the capital, operation and maintenance costs of projects. Environmental costs are economic losses that are caused by adverse impacts on the environment and that usually have not been taken sufficiently into account by the actors who caused these impacts. Resource costs refer to the costs of a non-optimal use of (water) resources (e.g. an inefficient allocation of water among different water users). Resource costs can be expressed through the (forgone or potential) economic benefits that could be achieved by a more efficient water management. The cost assessment of projects should cover these different cost categories as far as possible.

Cost-benefit analysis (CBA)

The purpose of the CBA is to determine a project with a maximum net-benefit. Usually the costs are compared with the benefits in along-term perspective (lifetime of the project). Discount rates play a crucial role in calculating the annual costs and benefits. Costs are often understood as forgone benefits (opportunity costs). One of the main limitations of the CBA is the difficulty to evaluate benefits of a project in economic terms. Economic benefits can also include prevented or saved costs due to a project. The willingness to pay approach is often applied to evaluate the benefits of projects in municipal water supply or in flood control. Change in net income is used, for instance, for estimating the benefits of an irrigation development project.

References:

Stephen Merret (1997): Introduction to the Economics of Water Resources, UCL Press, London. Colin Green (2003: Handbook of Water Economics - Principles & Practice, John Wiley & Sons, West Sussex, England.

Cost-effectiveness analysis (CEA)

The CEA aims to find out the least-cost strategy, for instance, to comply with a water quality standard.

References:

Stephen Merret (1997): Introduction to the Economics of Water Resources, UCL Press, London. Colin Green (2003: Handbook of Water Economics - Principles & Practice, John Wiley & Sons, West Sussex, England.

Data Assimilation, Updating (general)

Data assimilation provides an effective way to combine the models and observations that form the basis for hydro-meteorological forecasting. It handles tradeoffs between measurement accuracy, frequency, and resolution; adaptive estimation of model errors; sensitivity to incorrect statistical assumptions; white noise removal, identification of a general trend, phase shift adaptation, reconstruction of lost data (e.g. reconstruct a lost peak in an upstream discharge boundary. Simple and Ensemble Kalman Filtering techniques can be used.

References:

Madsen, H., M.B. Butts, S. T. Khu, SY. Liong, 2000 Data assimilation in rainfall runoff forecasting. Hydroinformatics 2000, 4th International conference on Hydroinformatics

Teuling, A.J., H. Leijnse, P.A. Troch, J. Sheffield and E.F. Wood (Eds) 2004, Proceedings of the 2nd international CAH-MDA workshop on: The Terrestrial Water Cycle: Modelling and Data Assimilation Across Catchment Scales, , pp. 170, Princeton, NJ, October 25–27

Examples:

http://projects.dhi.dk/daihm/river_flow.htm(Hartnack, J. and H.Madsen 2001 Data assimilation in river flow modelling , 4th

DHI Software conference in June 2001)

Data Uncertainty (HarmoniRiB)

Methodologies, tools and guidelines for assessing uncertainty in data is being developed within the EU RTD project "Harmonised Techniques and Representative River Basin Data for Assessment and Use of Uncertainty Information in Integrated Water Management (HarmoniRiB)"Material of particular interest available through www.harmonirib.com are:- A report with guidelines for assessing data uncertainty- A software tool (Data Uncertainty Engine - DUE)

References:

http://harmonirib.geus.info/index.shtml

Differential Split-sample Test

The differential split-sample test should be applied whenever a model is to be used to predict variables in a given gauged catchment under conditions different from those corresponding to the available data. The test may have several variants depending on the specific nature of the modelling study. If for example a simulation of the effects of a change in climate is intended, the test should have the following form. Two periods with different values of the climate variables of interest should be identified in the historical record, such as one with a high average precipitation, and the other with a low average precipitation. If the model, for instance, is intended for prediction of streamflow in a wet climate scenario, then it should be calibrated on a dry segment of the historical record and validated on a wet segment. Similar test variants can be defined for the prediction of changes in land use, effects of groundwater abstraction and other such changes. In general, the model should demonstrate an ability to perform through the required transition regime.

References:

Klemes, V. 1986. Operational testing of hydrological simulation models. Hydrological Sciences Journal, 31, 13-24.

Examples:

Refsgaard, J.C. and Knudsen, J. 1996. Operational validation and intercomparison of different types of hydrological models. Water Resources Research, 32(7), 2189-2202.

Double Mass Curves

Double Mass curves plot cumulative totals of a selected variate at site A against the same or another variate at site B. Changes in slope indicate changes in relationship between the variates or sites that may need to be investigated and accounted for.

References:

WMO (1994) Guide to hydrological Practices

Economic benefit assessment methodologies

For each of the different activities in water management the socio-economic benefits are to be determined. In case of water withdrawal and treatment, water delivery and water use, the value of water can be measured by using a) the production functions (= relationships between water input and volumes of products) and the product prices in agriculture and industries, b) water consumption and water prices for domestic use. The net-benefits are the differences between the benefits and costs of water (withdrawal, treatment, delivery, use). The economic benefits of reducing wastewater effluents or water pollution can be assessed by cost savings, for instance, in drinking water treatment, in development of remote or alternative water sources (e.g. reservoirs) and in industrial water use. The non-economic benefits, such as conservation of aquatic ecosystems resulting from a reduced wastewater discharge, can be evaluated by surveying the stakeholders or societal groups concerned. The socio-economic benefits of flood control measures can be assessed by using the damage costs (incl. averting costs and indirect economic losses) prevented and, if applicable, by questioning the people and governmental institutions for their willingness to pay for flood mitigation options. Again, the net-benefits of flood control measures is the difference between their costs and benefits. Probability values of flood excedences and appropriate discount rates for the periods in question are to be used.

Economic optimisation models

Currently, there are only a few approaches that combine water models with socio-economics. The CALVIN water management model is one of the examples that demonstrates the incorporation of socio-economics in the optimisation of water supply systems on river basin level. Another example is the hydro-economic model DSS AQUATOOL developed in the Jucar Pilot River Basin, Spain. The subject of the Expert Meeting on Economics in Water Management Models on 15-16 November 2004 in Copenhagen were the methodologies applied in coupling water models with socio-economics. Similar events are the workshop on Integrated River Basin Modelling & the EU Water Framework Directive on 17-18 November 2005 in Amsterdam and the International Workshop on Hydro-Economic Modeling and Tools for the Implementation of the European Water Framework on 30-31 January 2006 in Valencia.

References:

CALVIN model: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/.DSS
AQUATOOL: http://www.upv.es/aquatool/index_E.htm.EU
Workhop on hydro-economic models, Copenhagen, 15-16 November 2004: http://hit.infu.uni-dortmund.de/login.html (userid: Copenhagen, password: EconoMod.
Workshop on Integrated River Basin Modelling & the EU Water Framework Directive on 17-18 November 2005 in Amsterdam: http://www.falw.vu.nl/ivm/watereconomics.International
Workshop on Hydro-Economic Modeling and Tools for the Implementation of the European Water Framework on 30-31 January 2006 in Valencia:http://www.upv.es/aquatool/jornadas.

Ensemble Prediction

A special case of multiply scenario analysis is the ensemble prediction technique. In hydrological terms, a process whereby a continuous hydrologic model is successively executed several times for the same forecast period by use of varied data input scenarios, or a perturbation of a key variable state for each model run. A common method employed to obtain a varied data input scenario is to use the historical meteorological record, with the assumption that several years of observed data covering the time period beginning on the current date and extending through the forecast period comprises a reasonable estimate of the possible range of future conditions.

References:

Georgakakos, K.P., and R. Krzysztofowicz, (eds.), 2001: Special Issue on Probabilistic and Ensemble Forecasting. Journal of Hydrology, 249, 1-196S.

Maskey, V. Guinot & R. K. Price (2003) Propagation of precipitation uncertainty through a flood forecasting model. In: Weather Radar Information and Distributed Hydrological Modelling Eds:Yasuto Tachikawa, Baxter E. Vieux, Konstantine P. Georgakakos & Eiichi Nakakita IAHS Publ. 282 (2003) 93-100

Examples:

Herr, H., E. Welles, M. Mullusky, L. Wu, J. Schaake,2002, “Simplified Short Term Precipitation Ensemble Forecasts: Theory,” Preprints of the Symposium on Observations, Data Assimilation and Probabilistic Prediction, 82nd AMS Annual Meeting, Orlando, Florida.

Error Prediction

The error term has to be modelled to allow predictions of its short term realizations, which is often done through time series analysis (e.g., the Box and Jenkins family of linear models) that makes use of the fact that model residuals are often strongly auto-correlated. Error prediction or forecast output updating is carried out by using simple statistical adjustment techniques and time series analysis tools (e.g. AR or ARMA) or by sophisticated data based forecast method (e.g. neural networks). Sometimes it is more efficient than the use parameter updating schemes.

References:

Anctil, F.; Perrin, C. ; Andreassian, V., 2003 : ANN output updating of lumped conceptual rainfall/runoff forecasting models1, Journal of the American Water Resources Association, Oct 2003

Schreider, S. Y., P. C. Young, and A. J. Jakeman, 2001. An Application of the Kalman Filtering Technique for Streamflow Forecasting in the Upper Murray Basin. Mathematical and Computer Modelling 33:733-743

Error Propagation Equation

This method is based on the classic analytical equations for error propagation (well known by most students of the experimental sciences) where variances of independent variables are added. The method is quick and requires few resources, and may therefore be useful for initial screening of uncertainties. The conditions imposed for use of the error propagation equation are:- The uncertainties are relatively small, the standard deviation divided by the mean value being less than 0.3;- The uncertainties have Gaussian (normal) distributions;- The uncertainties have no significant covariance.

References:

IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC, 2000.http://www.nusap.net/sections.php?op=viewarticle&artid=17

Examples:

References to examples can be found at: http://www.nusap.net/sections.php?op=viewarticle&artid=17

Event Validity

Rykiel (1996) describes two alternative interpretations of event validity. Firstly, it may be defined as the process when a comparison between the model and system is made of the occurrence, timing, magnitude and form of events. Secondly, it may be interpreted as qualitative validation in which the model is tested for its ability to reproduce the proper relationships among model variables and their dynamic behaviour rather than to accurately reproduce their quantitative values.

References:

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

Expert Elicitation

Expert elicitation is a structured process to elicit subjective judgements from experts. It is widely used in quantitative risk analysis to quantify uncertainties in cases where there is no or too few direct empirical data available to infer on uncertainty. Usually the subjective judgement is represented as a ‘subjective’ probability density function (pdf) reflecting the experts degree of belief.

References:

Papers and websites:H.C. Frey, 1998, BRIEFING PAPER PART 1: Introduction to Uncertainty Analysis. (http://legacy.ncsu.edu/classes/ce456001/www/Background1.html)http://www.nusap.net/sections.php?op=viewarticle&artid=17

Examples:

References to examples can be found at: http://www.nusap.net/sections.php?op=viewarticle&artid=17

Expert Evaluation of Model Performance

Two different approaches for making use of expert knowledge and experience in evaluating the credibility of a model performance are:- Turing tests: Experienced people are asked as to whether they can discriminate between outputs from the system and the model (Rykiel, 1996)- Face validity: Experienced modellers are asked if the model and its functioning are reasonable (Rykiel, 1996)

References:

Mayer, D.G. and Butler, D.G., 1993. Statistical validation. Ecol. Model., 68, 21-32.

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

Sargent, R.G. 1984. A tutorial on verification and validation of simulation models. In: S. Sheppard, U. Pooch and D. Pegden (Eds), Proceedings of the 1984 Winter Simulation Conference, IEEE 84CH2098-2, pp. 115-122.

Extreme-condition Test

Rykiel (1996) states that extreme-condition tests check that the model structure and output are plausible for extreme or unlikely combinations of factors in the system.

References:

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

Finite Difference

Finite difference is a method for spatial discretisation of the model area. A finite difference grid is constructed covering the entire model area, consisting of grid cells arranged in rows, columns and layers. Variable cell dimensions may be applied to construct irregular grids, by which a finer resolution can be obtained in areas of particular interest.

References:

Kinzelbach, W. (1986). Groundwater modelling. An introduction with Sample Programs in BASIC, Elsevier.

Finite Element

Finite element is method for spatial discretisation of the model area. A finite element mesh consists of nodes that are connected by line elements to form elements (finite elements). In theory the elements in a mesh may take any form (e.g. triangular, rectangular, quadrilateral) and any combination of different forms. Finite element meshes are thus highly flexible and very complex geometries may be represented.

References:

Istok, J. (1989) Groundwater modeling by the Finite Element Method, American Geophysical Union, Water Resources Monograph 13.

Genetic Algorithms

Other robust methods with a recent popularity are called genetic Algorithms (GA). They are very robust like CRS or PRS. They resemble other methods, like PRS and CRS, by storing a set of parameter vectors with evaluations of the objective function. The terminology is borrowed from genetics, but like PRS and CRS these are too much based on ”brute force” in the eyes of mathematicians and OR-researchers. Their robustness and their speed of convergence make these methods popular. The concept of the method was initially proposed by Holland (1975). A comprehensive discussion is given in Goldberg (1989). Applications in hydrology were made e.g. by Wang (1991, 1997) and Franchini (1996).

References:

Franchini, M. (1996). Use of a genetic algorithm combined with a local search method for the automatic calibration of conceptual rainfall-runoff models. Hydrological Sciences Journal, 41(1), 21-39.

Goldberg D.E., 1989. Genetic algorithms in search, optimization, and machine learning, Addison-Wesley Publishing Company Inc., Reading, Massachusetts etc., 412 pp.

Holland, J. H. (1975). Adaptation in natural and artificial systems. Ann Arbor, Michigan, University of Michigan Press p.

Wang, Q. J. (1991). The genetic algorithm and its application to calibrating conceptual rainfall-runoff models. Water Resources Research, 27(9), 2467-2471.

Wang, Q. J. (1997). Using genetic algorithms to optimise model parameters. Environmental Modelling and Software, 12(1), 27-34.

Global behaviour

The global operation of each model needs to be checked. This means that the model must translate any changes in the input or in the operating variables into an altered output, which describes the behaviour of the system in an expected manner.

Infilling (temporal)

Infilling of gaps in data records due to gauge or operator malfunction is often required, especially as problems commonly occur in the extreme events that are of most interest and where valid data are most valuable. Infilling is also particularly important for continuous simulation models where it may not be possible to use records containing gaps. However, infilled data should always be clearly identified (e.g. using data quality flags or codes). There are many techniques for infilling, including:- Visualisation and manual curve-fitting- Simple linear or non-linear interpolation between known values- Use of surrogates – using ratios or relationships with other known variables (e.g. evaporation with temperature, or chemical pollutant concentrations with turbidity) - Correlation with neighbouring gauges- Spatial interpolation (contouring, surface fitting, etc)Spatial consistency can form an important part of infilling, and there is a clear link with spatial integration methods that estimate information at new or missing locations. However, spatial integration is described separately; infilling is used to describe working to improve temporal records at real locations, rather than interpolating whole records for new sites. Note also that infilling can itself be viewed as a modelling process, with Assimilation (described separately) providing one of the more detailed examples.

Interaction and Communication ABC

Interaction and communication may include, but are not necessarily limited to:- Advertisement, - Advisory body, - Article, - Brain box, - Co-knowing (advising median), - Conversation, - Co-operating (interactive media), - Corridor chat, - Co-thinking ("tapping" means), - Creative competition, - Creative sessions, - Design studio, - Electronic meeting, - Exhibition, - Expert meeting, - Fact sheets, - Fair, - Focus groups, - Games, - Guiding-group, - Individual stakeholder meeting, - Information evening, - Internal user group, - Internet site, - Interview - personal or by telephone - Joint fact-finding, - Intranet site, - Liaison, Newsletter, - Panel of citizens, - Participation, - Perceptiveness study, - Platform, - Poster, - Presentation, - Project team, - Public meeting, - Questionnaire, - Quiz, - Reminder, - Sounding board, - Vote, - Working conference or Working groups.

References:

EC (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document no. 8. Public Participation in relation to the Water Framework Directive. Produced by working group 2.9 Public Participation. Luxembourg 2003. 214 pp. http://europa.eu.int/comm/environment/water/water-framework/strategy2.pdfHarmoniCoP - Harmonizing Collaborative Planning http://www.harmonicop.info

Internal Validity

Described by Rykiel (1996) as, 'A test data set (initial conditions, parameter values, and input data for driving variables) can be shown to produce a consistent output each time the model is run'. This test is particularly applicable to stochastic models with varying selections of the same input data.

References:

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

Invited Tender with Pre-qualification

This is a two step procedure where the first step is an invitation for consultants to submit material documenting their capability to carry out the job. On this basis the Client selects the consultants (usually between 3 and 7) who are requested to submit a proposal. The first step (prequalification) may be open or invited.

References:

General regulations for tendering in EU

Invited Tender without Pre-qualification

A finite number of consultants are directly invited to prepare a proposal

References:

General regulations for tendering in EU

Manual Optimisation

Manual optimisation attempts to find the best fit between modelled and observed system response by trial and error and expert opinion. The results of earlier runs are used to gain insight into the influence of the various parameters on model performance. The parameter values are adjusted until the model fit (as defined by subjective assessment or the use of an objective function) falls within acceptable limits. The advantage of manual optimisation is that the modeller gains great feeling with the characteristics of the model (see also the sensitivity analysis). However, although an experienced modeller can achieve good results for problems, which are not too complex, this approach is not particularly reproducible. Moreover, it will seldom result in the true optimum of the objective function.

Mass Balance

Checking that the sum of all inputs equals the sum of all outputs (plus any increase in storage within the system and any losses within the system for a non-conservative ingredient) is fundamental to most modelling work, and should always be done. In modelling, a poor mass balance indicates a poor model (poor algorithm or poor data interval), though care may be needed to ensure that changes in storage and losses are properly accounted for. As a means to validate data, however, checking mass balance can be especially problematic. Precipitation data (rain and snow) can show large spatial variation, and gauge networks are frequently too sparse to make accurate estimates of areal inputs. Evapotranspiration is very difficult to measure directly, and can usually only be estimated from temperature, humidity and wind speed measurements at very sparsely distributed climate stations. Changes in soil water storage are rarely quantified, while groundwater recharge is often taken as the residual in a mass balance, possibly validated by sparse measurement of water tables and springflows. Measurements of pollutant inputs and outputs are possibly even rarer. Despite these problems, some attempt to check mass balances in data should be made. Aggregation will progressively smooth spatial and temporal aggregation, and using an annual timestep will minimise changes in catchment storage. Where flow data are available within a system (upstream and downstream), checks should be made that flow increases in a downstream direction (usually), and that volumes per unit area are distributed realistically (given how catchment characteristics may change).

Metadata table

An effective way to keep an overview of the status of required data is by constructing a table.

Model Appraisal

Relatively quick review carried out by a professional with experience in similar projects, but who is not necessarily a modelling expert.

Examples:

Evaluation of performance for the various modelling tasks, e.g. by use of the Checklist for Reviews/Audits/Appraisals (see this Method).

Model Audit

Audit carried out by a modelling expert with specific knowledge on the modelling tools used by the modeller. The audit comprises both a peer review of the report and a check of selected part of the model set-up and maybe some of the model runs. This implies that the auditor has access to the model set-up files and is able to carry out and analyse a few simulations.

Examples:

Evaluation of performance for the various modelling tasks, e.g. by use of the Checklist for Reviews/Audits/Appraisals (see this Method).

Modifications of input

Adjustment of input series, meteorological fields and/or river upper boundary conditions whenever it is justified.

Monte Carlo Simulation

Monte Carlo Simulation is a statistical technique for stochastic model-calculations and analysis of error propagation in calculations. Its purpose is to trace out the structure of the distributions of model output. In it's simplest form this distribution is mapped by calculating the deterministic results (realizations) for a large number of random draws from the individual distribution functions of input data and parameters of the model. To reduce the required number of model runs needed to get sufficient information about the distribution in the outcome (mainly to save computation time), advanced sampling methods have been designed such as Latin Hyper Cube sampling. The latter makes use of stratification in the sampling of individual parameters; like in random Monte Carlo sampling, pre-existing information about correlations between input variables can be incorporated. Monte Carlo analysis requires the analyst to specify probability distributions of all inputs and parameters, and the correlations between them. Both probability distributions and correlations are usually poorly known. All factors to be varied are varied simultaneously sampled from their statistical distribution, therefore not systematically. A relatively large number of runs are required and linear regression may subsequently be applied to determine the relationship between the model results and the factors. Unlike the classic sensitivity analysis, no assumptions need be made beforehand with regard to linearity. A number of software packages are available to do Monte Carlo analysis. Widely used are the commercial packages @Risk (http://www.palisade.com) and Crystal Ball (http://www.decisioneering.com/crystal_ball). Both are packages that are designed as fully integrated MS-Excel add-in programs with its own toolbar and menus.

These packages can be used with minimal knowledge on the sampling and calculations techniques itself, which makes Monte Carlo Assessment easy (but tricky because it allows incompetent use). Another commercial package is Analytica (http://www.lumina.com), which is a quantitative modelling environment with built-in Monte Carlo algorithms.If your model is not built in Excel you can use the SimLab package, which is freely available from the JRC (http://sensitivity-analysis.jrc.cec.eu.int/default2.asp?page=SIMLAB). SimLab can also be interfaced with Excel, but this requires some programming skills. For the UNIX and MS-Dos environments you can use the UNSCAM (Janssen et al., 1994) software tool. RIVM is presently developing a new tool for Monte Carlo analysis, USATOOL, which will run under Windows. Additionally most Monte Carlo analysis software offers the possibility to determine the relative contribution of uncertainty in each parameter to the uncertainty in a model output, e.g. by sensitivity charts, and can be used for a sophisticated analysis of trends in the presence of uncertainty.

References:

Papers and reportsBeven, K. and A.M. Binley (1992) The future role of distributed models: model calibration and predictive uncertainty. Hydrological Processes, 6, 279-298.

IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, IPCC, 2000.

McKay, M.D., W.J. Conover and R.J. Beckman (1979) A Comparison of Three Methods for Selection Values of Input Variables in the Analysis of Output From a Computer Code. Technometrics, 2, 239-245

Pebesma, E.J., G.B.M. Heuvelink, (1999) Latin Hypercube Sampling of Gaussian Random Fields. Technometrics 41 (4), 303-312.

http://www.nusap.net/sections.php?op=viewarticle&artid=17http://www.palisade.comhttp://www.decisioneering.com/crystal_ball

Examples:

Freeze, R.A. (1980) A stochastic-conceptual analysis of the rainfall-runoff process on a hillslope. Water Resources Research, 16(2), 391-408.

Kros, J., E.J. Pebesma, G.J. Reinds and P.A. Finke (1999) Uncertainty assessment in modelling soil acidification at the European scale: A case study. Journal of Environmental Quality, 28(2), 366-377.

Thorsen, M., J.C. Refsgaard, S. Hansen, E. Pebesma, J.B. Jensen and S. Kleeschulte (2001) Assessment of uncertainty in simulation of nitrate leaching to aquifers at catchment scale. Journal of Hydrology, 242, 210-227.

Multi-criteria analysis (MCA)

The MCA is an appropriate tool for assessing the impacts of a project by considering also non-monetary effects. There are various methods to determine the relative weights of criteria or performance of different (sometimes conflicting) objectives of a project.

References:

Stephen Merret (1997): Introduction to the Economics of Water Resources.UCL Press, London.

Colin Green (2003): Handbook of Water Econmics - Principles & Practice.John Wiley & Sons, West Sussex, England.

Multistart and Clustering Methods

Multistart methods uses many random parameter vectors and evaluate a objective function by running the model with each parameter vector. In order to avoid starting from almost the same point (= the same parameter vector) one can use 'clustering methods' (see Rinnooy Kan, A.H.G. and G.T. Timmer, 1987. Stochastic global optimization methods: I Clustering methods, Mathematical Programming, 39: 27-56.This method is almost always combined with a local search method (see 'Combined methods'). The method is discussed by Hendrix E.M.T (1998). Global optimization at work, WAU, Wageningen, 248 pp.

NUSAP

NUSAP is a notational system proposed by Funtowicz and Ravetz (1990), which aims to provide an analysis and diagnosis of uncertainty in science for policy. It captures both quantitative and qualitative dimensions of uncertainty and enables one to display these in a standardized and self-explanatory way. It promotes criticism by clients and users of all sorts, expert and lay and will thereby support extended peer review processes. The basic idea is to qualify quantities using the five qualifiers of the NUSAP acronym: Numeral, Unit, Spread, Assessment, and Pedigree. By adding expert judgment of reliability (Assessment) and systematic multi-criteria evaluation of the production process of numbers (Pedigree), NUSAP has extended the statistical approach to uncertainty (inexactness) with the methodological (unreliability) and epistemological (ignorance) dimensions. By providing a separate qualification for each dimension of uncertainty, it enables flexibility in their expression. By means of NUSAP, nuances of meaning about quantities can be conveyed concisely and clearly, to a degree that is quite impossible with statistical methods only.

References:

Handbook:Funtowicz, S.O. and Ravetz, J.R., 1990. Uncertainty and Quality in Science for Policy. Dordrecht: Kluwer.
Websites:http://www.nusap.net

Examples:

References to examples can be found at: http://www.nusap.net/sections.php?op=viewarticle&artid=17

OpenMI

The Open Modelling Interface and Environment (OpenMI) is a framework that supports the linkage of individual models with different domains. The OpenMI consists of standards and protocols for exchange of data when coupling models and supporting software. OpenMI was developed by the EU research project HarmonIT (2002-2005).

References:

OpenMI: http://www.harmonit.org.

Open Tender

The tender is announced publicly and everybody is invited to submit proposals

References:

General regulations for tendering in EU

Parameter Ranges in Sensitivity Analysis

When changes in model input (initial conditions, parameters, sometimes also decision variables) lead to either no change or extreme changes in model behaviour, the model structure may require reconsideration. However, the results of a sensitivity analysis depend strongly of the variation in the inputs, which are used in the sensitivity analysis. The changes used in the sensitivity analysis must be realistic and represent what is known. Sometimes the uncertainty in the input is known as a range only, while for other inputs full statistical distributions are available. In calibration the knowledge on uncertainty is more important than in sensitivity analysis. For sensitivity analysis, the following ways are more or less standard to vary model input:- Draw from the statistical distribution a certain number of values- Use a nominal value of the input and +/- a fixed percentage of this nominal value- Use a nominal value of the input and +/- a fixed percentage of the standard deviation- Use the range of the input and divide this range equidistantly in (limited) number of values, typically 3, 4, ..., 10- Use the range of the input as minimum and maximum value for this inputInputs can be varied each in its own way, thus not necessarily all in the same way.

Peer Review

Thorough review carried out by an experienced modeller on the basis of reports and other information provided by the modeller.

Examples:

Evaluation of performance for the various modelling tasks, e.g. by use of the Checklist for Reviews/Audits/Appraisals (see this Method).

Potential Evapotranspiration Estimation

PE is not a measured variable but assessed from equations and formulas. At the catchment scale, several PE estimation method may prove suitable. Simple methods involving only a few climatic variables may be preferred given restrictions in data availability (to more complex formulas (e.g. Penman). Climatic variables generally used are: temperature, wind speed, solar radiation and relative air humidity. Several types of methods exist:- those based on temperature- those based on radiation- those that combine aerodynamic and energetic approaches.

References:

Allan, R.G., L.S. Pereira, D. Raes and M. Smith (1998) Crop evapotranspiration. Guidelines for computing crop water

requirements.FAO Irrigation and Drainage Paper, 56, FAO. Rome.

Morton, F. I. (1983). Operational estimates of actual evapotranspiration and their significance to the science and practice of hydrology. Journal of Hydrology, 66, 1-76.

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. Proc. R. Soc. London, A193, 120-145.

Priestley, C. H. B. and Taylor, R. J. (1972). On the assessment of surface heat fluxes and evaporation using large-scale parameters. Monthly Weather Review, 100, 81-92.

Thornthwaite, C. W. and Mather, J. R. (1955). The water balance. Publ. Climatol. Lab. Climatol. Drexel. Inst. Techol., 8(1), 1-104.

Proposal Evaluation

The proposal is evaluated according to compliance with the Terms of References. A supporting Excel based tool may be used to support the evaluation. The example-questions below, where the numbers in white cells should be filled out by the water manager and the evaluator, may serve as inspiration.

	Modelling step / Issue	**Weight (to be provided by the manager beforehand)**		**Max score**	**Evaluation - actual score**	**Weighted proposal score (Max = 100%)**	**Score guidance**			
		Step	**Within step**				**Score 0**	**Score 1**	**Score 3**	**Score 5**
	Step 1: Model Study Plan	5				3,5				
1.1	Are the project objectives clearly defined?		10	5	3	0,3	Missing	Deficient	Adequate	Very Good
1.2	Are the modelling approach and complexity clearly defined?		15	5	4	0,6	Missing	Deficient	Adequate	Very Good
1,3	Are the accuracy criteria clearly defined?		5	5	1	0,1	Missing	Deficient	Adequate	Very Good
1.4	Are the sources of uncertainty clearly defined and incorporated into the modelling approach?		10	5	1	0,1	Missing	Deficient	Adequate	Very Good
1.5	Are the roles of stakeholders and public clearly defined and their views taken into account?		10	5	3	0,3	Missing	Deficient	Adequate	Very Good
1.6	Are requirements for archiving datasets, model setup and results clearly defined?		5	5	5	0,3	Missing	Deficient	Adequate	Very Good
1.7	Are the final products from the modelling study clearly defined?		5	5	4	0,2	Missing	Deficient	Adequate	Very Good
1.8	Are the resources available for the project enough to achieve the objectives within the available time?		10	5	5	0,5	Missing	Deficient	Adequate	Very Good
1.9	Have appropriately qualified staff been selected to supervise and run the modelling work?		30	5	4	1,2	Missing	Deficient	Adequate	Very Good

Proxy Basin Test

The proxy-basin test should be applied when there is not sufficient data for a calibration of the catchment in question. For example, if streamflow has to be predicted in an ungauged catchment Z, two gauged catchments X and Y within the region should be selected. The model should be calibrated on catchment X and validated on catchment Y and vice versa. Only if the two validation results are acceptable and similar can the model command a basic level of credibility with regard to its ability to simulate the streamflow in catchment Z adequately.

References:

Klemes, V. (1986) Operational testing of hydrological simulation models. Hydrological Sciences Journal, 31, 13-24.

Examples:

Refsgaard, J.C. and Knudsen, J. (1996) Operational validation and intercomparison of different types of hydrological models. Water Resources Research, 32(7), 2189-2202.

Andersen, J., J.C. Refsgaard and K.H. Jensen (2001) Distributed hydrological modelling of the Senegal River Basin. Model construction and validation. Journal of Hydrology, 247, 200-214.

Proxy Basin Differential Split-sample Test

The proxy-basin differential split-sample test is the most difficult test for a model, because it deals with cases where there is no data available for calibration and where the model is directed to predicting non-stationary conditions. An example of a case that requires such a test is simulation of hydrological conditions for a future period with a change in climate and for a catchment, where no calibration data presently exist. The test is a combination of the proxy basin and the differential split-sample tests.

References:

Klemes, V. (1986) Operational testing of hydrological simulation models. Hydrological Sciences Journal, 31, 13-24.

Examples:

Refsgaard, J.C. and Knudsen, J. (1996) Operational validation and intercomparison of different types of hydrological models. Water Resources Research, 32(7), 2189-2202.

Pumping tests and slug tests

Estimation of the hydraulic properties (Transmissivity and storage coefficient) is often estimated on the basis of pumping tests or slug tests. Pumping tests are carried out by pumping from a well at a specified rate, and measuring the hydraulic head continuously in monitoring wells. Slug tests are initiated by causing an instantaneous change in the water level in a well through a sudden introduction or removal of a known volume of water. The recovery of the water level in the well with time is then observed. For both methods the observed change in the hydraulic head is then analysis by type curve matching to derive the transmissivity and/or the storage coefficient. Slug tests are usually carried out in small diameter wells and do only reflect the properties in the very vicinity of the wells. Pumping test have, generally, a much larger area of influence, and thus provide estimates of the mean properties of a larger area.

References:

Freeze RA and Cherry JA (1979) Groundwater. Prentice Hall, New Jersey. Butler, J.J., Jr., 1998. The Design, Performance, and Analysis of Slug Tests, Lewis Publishers, Boca Raton, 252p

Pure Random Search

This method is 'Monte Carlo'-like. It is very robust and it requires no partial derivatives, but it requires much computer time. In short it works like this. Vary all parameters randomly, run the model and evaluate the objective function. Is the latter better than the best until now, replace it with the new one. The convergence rate of the method is very slow, but for simple models one might find sufficient accuracy of the model in a finite amount of time. If not only the best parameter vector is stored, but a set of best vectors, one can use these final set of parameter vectors to investigate the resulting uncertainty by Monte Carlo runs.

Qualitative Performance Measures

Performance measures (indicators) provide lumped measures of calibration that do not indicate the spatial or temporal distribution of the error. In addition to these measures, it is important to show that there is no systematic error involved in the spatial distribution of differences between modelled and measured variables. The simplest way to do this is to present a scatter diagram or a contour plot of measured modelled variable, posting residuals, which can be analysed.

Rating curves

Rating curves (or Stage-Discharge curves) are found by plotting field gaugings of riverflow (discharge) at a site against corresponding water levels (stage). The curves are then used to convert time-series of river level data to flow. Numerical curve fitting may be used to develop Rating equations over the full or partial ranges of level data. Excessive scatter or temporal changes in the relationship between flow and level can have a large impact on the derived flow data, and must be investigated and explained. The relationship at high flows is particularly important, and the risk of bypassing should be considered (see method Site visits and photographs)

References:

Herschy R W (1995) Streamflow measurement, E & F N Spon, London.

Regionalized Sensitivity Analysis

This method is also denoted Hornberger-Spear-Young method.By running the model a number of times (Monte Carlo) and segmenting the runs into acceptable and unacceptable, two empirical distributions are found, after which the distributions can be used further in order to estimate a value for the sensitivity.

Register of Ecological Models

The Register of Ecological Models (REM) is a meta-database for existing mathematical models in ecology. It provides general, technical and mathematical information about models, as well as references and Internet links.

References:

Register of Ecological Modelshttp://eco.wiz.uni-kassel.de/ecobas.html

Regression Techniques

In cases where the model parameters are assessed through automatic calibration (inverse modelling) the uncertainty of the model parameters are usually also derived. On this basis it is some times possible to assess the uncertainty of prediction variables, for which observation data were used during the calibration. In this approach the effects of different uncertainty sources are lumped together and only the total uncertainty is assessed.

References:

Christensen, S. and R.L. Cooley (1999) Evaluation of prediction intervals for expressing uncertainties in groundwater flow model predictions. Water Resources Research, 35(9), 2627-2639.

Resampling Techniques

Dedicated ensemble methods (e.g. JackKnife, Bootstrap, GLUE) are available to derive from one original data set a large ensemble of new data sets to assess uncertainty.

References:

Beven, K. and Binley, A. (1992). The future of distributed models: model calibration and uncertainty prediction. Hydrological Processes, 6(3), 279-298.

Response Surface Method

A meta-model is made of the model, which is linear in the coefficients and often comprises a first or second order of Taylor series approach. Interactions between the factors are not accounted for in the former case, but are accounted for in the latter. However, the meta-model must still be validated, through cross validation, for example.

Robustness

In a robustness test, the model is fed with extreme values in order to find out which conditions cause it to crash (or show other undesirable behaviour). Most of the work involves the choice of a limited number of interesting input sets. This exercise is not really necessary in commonly used models, because the scope of the model is then known precisely, i.e. there is knowledge of the conditions under which the model may be used. The model program manual can also (partially) provide directional instructions for this process.

Scatter plots

Scatter plots are sometimes used to describe plots of gauged flow velocity against flow depth at sites where both are measured continuously (because variable backwater or shifting controls mean that a stable Rating may not exist). Scatter plots are used to identify extreme or unaccountable scatter. Scatter is not necessarily problematic (if the velocity and depth data are credible), provided it is not caused by random hydraulic instability.

References:

WRc(1987) A guide to short term flow surveys of sewer systems, Water Research Centre, UK

Scenario Analysis

Scenario analysis is a method that tries to describe logical and internally consistent sequences of events to explore how the future might, could or should evolve from the past and present. The future is inherently uncertain. Through scenario analysis different alternative futures can be explored and thus uncertainties addressed. As such, scenario analysis is also a tool to deal explicitly with different assumptions about the future. Several definitions of scenarios can be found in the literature. In the definition of UNEP (2002), the uncertainty aspect is explicitly incorporated. “Scenarios are descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out and what new factors will come into play”. Another definition is the following: A scenario is a description of the present state of a social and or natural system (or a part of it), of possible and desirable future states of that system along with sequences of events that could lead from the present state to these future states (e.g. Jansen Schoonhoven and Roschar, 1992). Other definitions also include the purposes of the use of scenarios. Van Notten (2002) defines scenarios as “descriptions of possible futures that reflect perspectives on past, present, and upcoming developments in order to anticipate the future”. Different types of scenarios exist. Alcamo (2001) discerns baseline vs. policy scenarios, exploratory vs. anticipatory scenarios and qualitative vs. quantitative scenarios.

- Baseline scenarios (or reference-, benchmark- or non-intervention scenarios) present the future state of society and environment in which no (additional) environmental policies do exist or have a discernable influence on society or the environment. Policy scenarios (or pollution control-, mitigation- or intervention scenarios) depict the future effects of environmental protection policies.
- Exploratory scenarios (or descriptive scenarios) start in the present and explore possible trends into the future. Anticipatory scenarios (or prescriptive or normative scenarios) start with a prescribed vision of the future and then work backwards in time to visualise how this future could emerge.
- Qualitative scenarios describe possible futures in the form of narrative texts or so-called “story-lines”. Quantitative scenarios provide tables and figures incorporating numerical data often generated by

sophisticated models. Finally scenarios can be surprise-free or trend scenarios, which extend foreseen developments, on the one hand or including surprises and exploring the extremes (e.g. best case / worst case) on the other hand.

References:

Alcamo J. (2001) Scenarios as tools for international environmental assessments. Environmental issues report. Experts corner report. Prospects and Scenarios No.5, European Environment Agency, Copenhagen

P. Jansen Schoonhoven and F.M. Roschar, Werken met scenario's; ook kwalitatieve informatie is te verwerken. Beleidsanalyse 1, p. 146-153, 1992.

Van Notten, P. (2002) Foresight in the face of scenario diversity. Paper presented at the international conference Probing the Future: developing organizational foresight in the knowledge economy, 11-13 July 2002 Glasgow.

UNEP (2002) Global Environmental Outlook 3: Past, present and future perspectives, Earthscan.

http://www.nusap.net/sections.php?op=viewarticle&artid=17

Sensitivity Analysis

Sensitivity analysis (SA) is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation, and of how the given model depends upon the information fed into it (Saltelli et al., 2000). Three types of sensitivity analysis can be distinguished:- Screening, which is basically a general investigation of the effects of variation in the inputs but not a quantitative method giving the exact percentage of the total amount of variation that each factor accounts for. The main purpose of screening methods is to identify in an efficient way a short list of the most important sensitive factors, so that in a follow-up uncertainty analysis the limited resources can be used in the most efficient way.- Local SA, the effect of the variation in each input factor when the others are kept at some constant level. The result is typically a series of partial derivatives - or an approximation thereof-, one for each factor, that defines the rate of change of the output relative to the rate of change of the input.- Global SA, the effects on the outcomes of interest of variation in the inputs, as all inputs are allowed to vary over their ranges. This can be extended to take into account the shape of their probability density functions. This usually requires some procedure for sampling the parameters, perhaps in a Monte Carlo form, and the result is more complex than for local SA. In their book, Saltelli et al. (2000) describe a range of different statistics describing how this type of information can be summarized. Global SA is a variance-analysis based method, using indices expressing the contribution of parameters to the variance in the output (e.g. standardized rank correlation coefficients and partial rank correlation coefficients) (cf. Saltelli et al. 2000).

References:

Andrea Saltelli, Karen Chan, Marian Scott, Sensitivity Analysis John Wiley & Sons publishers, Probability and Statistics series, 2000.

Andrea Saltelli, Stefano Tarantola, Francesca Campolongo, Marco Ratto, Sensitivity Analysis in Practice: A Guide to Assessing Scientific Models, John Wiley & Sons publishers, 2004 (Where the Saltelli et al. 2000 book provides the theoretical basis, this book is a comprehensive practical compendium of recommended methods tailored to specified settings, built around a set of examples and the freely available SIMLAB software.).

Websites- http://sensitivity-analysis.jrc.cec.eu.int/default.htm- http://www.nusap.net/sections.php?op=viewarticle&artid=17SoftwareAvailable software for sensitivity analysis includes:- SIMLAB: http://sensitivity-analysis.jrc.cec.eu.int/default2.asp?page=SIMLAB

Site visits and Photographs

Field visits and photographic records provide a large amount of knowledge and information that can be difficult to quantify, but are vital for placing model studies in context. They provide appreciation of, for example:- Topographical relationships between watercourses, floodplains and watersheds- Land use, point and non-point pollutant sources, and ecological conditions- Exposure, representativeness and maintenance of climate stations and raingauges- Condition and likely capacity of watercourses- Conditions at flow gauges, including operation and maintenance practices, hydraulic accuracy/effectiveness, and risk of bypassing during floods- Representativeness of water quality and biota monitoring sitesThis information contributes to model conceptualisation, set-up, and soundness assessments.

Sole Source

Direct negotiation between client and consultant

Examples:

This method is commonly used for small jobs and for expanding existing jobs. It is also the method that is used in case the modeller and the manager belong to the same organisation and no outsourcing of the modelling job takes place.

Spatial Interpolation and Integration

Generating spatially distributed or integrated information from at-site records is essentially similar to infilling, but in space rather than time. Techniques available include:- Visualisation, manual contouring, and deriving areas between contours- Zonation - using constant values for each zone of influence (e.g. sub-catchment, soil type, land use, habitat area, postal area, or 'Theissen Polygon' surrounding a raingauge)- Use of surrogates – using ratios or relationships with other variables whose spatial distribution is better defined (e.g. event rainfall with altitude or as a proportion of annual rainfall, pollutant washoff with land slope, or)- Surface fitting, including interpolation, gridding and contouring based on interpolation procedures.(e.g. areal rainfall estimation based on rainfall grids found by inverse distance weighted interpolation using the nearest three surrounding raingauges)Zonation, contouring and surface fitting are described as separate methods.

Split-sample Test

The split-sample test is the classical test, being applicable to cases where there is sufficient data for calibration and where the catchment conditions are stationary. The available data record is divided into two parts. A calibration is carried out on one part and then a validation on the other part. Both the calibration and validation exercises should give acceptable results.

References:

Klemes, V. 1986. Operational testing of hydrological simulation models. Hydrological Sciences Journal, 31, 13-24.

Andersen, J., J.C. Refsgaard and K.H. Jensen 2001. Distributed hydrological modelling of the Senegal River Basin. model construction and validation. Journal of Hydrology, 247, 200-214.

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

Power, M., 1993. The predictive validation of ecological and environmental models. Ecol. Model., 68: 33-50.

Examples:

This is a standard method used in numerous cases

Stability Test

After all warnings and errors have been check and possibly eliminated a stability test of HD models should be performed before other tests, such as mass error etc. In the stability test, results are saved for each time step and analysed possibly oscillations. This may be done from visual inspection of graphs showing discharge hydrographs for all computational points. In case of oscillations these must be removed prior to the simulations, e.g. by decreasing the time step, check of cross-sections where oscillations are observed. Oscillations may be systematic and only observable if every time-step is saved. Saving only every 2nd or 10th time-step may result in saving only the upper or lower amplitude of the oscillations, whereby the oscillation is not recognised. This test leads to quite large result files, which could be deleted after this test.

Stakeholder Summary Table

Draw up the analysis in a stakeholder table with the following six columns: - Identify and list all potential stakeholders- Identify their interests (overt and hidden) in relation to the problems being addressed by a project and its objectives (each may have several interests). - Estimate attitude and confidence using a selected scale, for instance with five categories describing the possible actions which are investigated: strongly in favour, weakly in favour, undecided, weakly opposed, and strongly opposed. - Briefly assess the likely impact of the project on each of these interests (positive, negative or unknown)- Indicate the relative priority which the project should give to each stakeholder in meeting their interests- Assess whether there are other groups or individuals that might influence the stakeholder to support your initiativeThis may require to bring needed people to the table and invite them to group meetings. It may take more than a simple announcement in the local paper and may require to personally contact key individuals and professional stakeholders on the telephone. Different strategies will probably have to be considered to get stakeholder support and reduce opposition.

References:

EC (2003) Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance document no. 8. Public Participation in relation to the Water Framework Directive. Produced by working group 2.9 Public

Participation. Luxembourg 2003. 214 pp. http://forum.europa.eu.int/Public/irc/env/wfd/library?l=/framework_directive/guidance_documents/0publishedsguidancesdocu&vm=detailed&sb=Title

Standard Performance Measures

Quantitative calibration performance generally relates to the calculation of residuals at targets and associated statistics for entire model area or subarea of this (e.g. layer). Quantitative calibration performance measures can by anything from residuals, sum of residuals, mean sum of residuals, sum of squares, root mean squares, coefficient of determination or scaled measures of these. It is important to select 3-4 different measures in order to cover both mean, max and minimum values of simulated mass flux or state variables.

References:

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

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

State Space Techniques

The state space theory and the Kalman filtering technique are powerful mathematical tools originally developed within the field of statistical control theory for linear systems, but later extended to comprehend non-linear systems. The key model variables are recognised as stochastic variables that are parameterised in terms of their mean and standard deviations. The input variables (e.g. climate data) are similarly described by a mean value (the recorded value) and a standard deviation (the uncertainty). In this way it is possible to calculate how uncertainty on, for example, input data propagates through the model and causes uncertainties on model state variables and output results. A disadvantage with this method is that it requires a reformulation of the model code, so that it is built into a state space formulation framework. A way to avoid this is by using an Ensemble Kalman Filter, where the covariance matrix is assessed through a Monte Carlo approach.

References:

Ahsan, M. and K.M. O'Conner (1994) A reappraisal of the Kalman filtering technique, as applied in river flow forecasting. Journal of Hydrology, 161, 197-226.

Evensen, G. (1994) Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte Carlo methods to forecast error statistics. Journal of Geophysical research, 99(C5), 10143-10162.

Gelb, A. (Ed.) (1974) Applied optimal estimation. MIT Press, Cambridge, Mass.

Examples:

Georgakakos, K.P., J. Rajaram and S.G. Li (1988) On improved operational hydrologic forecasting of streamflows. IIHR Report No. 325, Department of Civil Engineering and Iowa Institute of Hydraulic Research, The University of Iowa.

Kitanidis, P.K. and R.L. Bras (1978) Real-time forecasting of river flows. Technical Report 235. Ralph M. Parson's

Laboratory for Water Resources and Hydrodynamics, MIT, Cambridge, Mass.

Refsgaard, J.C., D. Rosbjerg and L.M. Markussen (1983) Application of Kalman filter to real-time operation and uncertainty analyses in hydrological modelling. IAHS Publication, 147, 273-282.

Storm, B. K.H. Jensen and J.C. Refsgaard (1988) Estimation of catchment rainfall uncertainty and its influence on runoff prediction. Nordic Hydrology, 19, 77-88.

State Variable Updating

Current states of the modelled drainage basin may deviate from the average conditions simulated by the model. The state-space-based Kalman filter is often used for linear systems to achieve such updating. It can also be extended to the nonlinear case by linearization (extended Kalman filter). Due to the fact that the stability of the latter approach is not guaranteed careful use is advised.

References:

Lee, Y. H. and V. P. Singh, 1998. Application of the Kalman Filter to the Nash Model. Hydrological Processes 12:755-767.

O'Connell, P. E. and R. T. Clarke. 1981. Adaptive Hydrological Forecasting: A Review. Hydrological Sciences Bulletin 26(2): 179-205.

Szollosi-Nagy 1985 Tanizaki, H., 1996. Nonlinear Filters: Estimation and Applications (Second Edition). Springer, Berlin, Germany.

Examples:

Tucci, C. E. M. and R. T. Clark, 1980. Adaptive Forecasting With a Conceptual Rainfall-Runoff Model. In: Hydrological Forecasting, International Association of Hydrological Sciences, Publication 129, pp. 445-454.

Statistical Validation

Rykiel (1996) describes how statistical validation includes a variety of tests performed during model calibration and operation. Three cases occur most often: (1) model outputs should have the same statistical properties as observations from the real system; (2) errors associated with critical output variables fall within specified or acceptable limits; and (3) several models are evaluated to determine which best fit the available data.

References:

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

Surface Fitting

Surface fitting can be used as a means of spatial interpolation and as a first stage in contouring. A range of techniques are available, but they are usually computationally intensive, and are best applied using GIS or other suitable software. Some techniques will fit the data at observation sites exactly, while others will find a best fit smooth surface that minimises overall errors at observation sites. Various techniques may be assessed before choosing one on essentially subjective grounds. The options include:- fitting a surface of selected order, usually by minimising the combined global error at data points; generating values on a grid or TIN (Triangulated Irregular Network) as required- using piecewise surfaces (splines) that fit elevations and preserve surface slope at local data points; generating values on a grid or TIN as required- generating values on a grid or TIN as weighted means of the nearby observations- generating values on a grid or TIN by krigging, which determines an optimum set of gauge weights based on analysis of the semi-variogram (the relationship between the variance of the difference between data points and their distance apart)

Thiessen Polygon Method

Thiessen polygons define individual areas of influence around each of a set of points (e.g. raingauges). Thiessen polygons are polygons whose boundaries define the area that is closest to each point relative to all other points. They are mathematically defined by the perpendicular bisectors of the lines between all points. This method may be used for catchment areal rainfall estimation.

References:

Thiessen, A.H. (1911). Precipitation for large areas. Mon. Weath. Rev., 39, 1082-1084.

Traces

Rykiel (1996) describes 'Traces' as the validation test during which, 'The behaviour of specific variables is traced through the model and through simulations to determine if the behaviour is correct and if necessary accuracy is obtained'.

References:

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

Uncertainty Matrix

The purpose of an uncertainty matrix is to provide a tool by which to get a systematic and graphical overview of the essential features of uncertainty in relation to the use of models in decision support activities. The idea is to identify the location, level and nature of the uncertainty associated with models, so that model developers and users will become aware of and address all of the important elements of uncertainty.The vertical axis of the matrix identifies the location of uncertainty, i.e. where the uncertainty is located in the modelling project framework:- Context (natural, technological, economic, social and political representation)- Model (model structure, technical model)- Inputs (driving forces, system data)- Parameters- OutcomesThe horizontal axis represents the level and nature of uncertainty:- Level (statistical uncertainty, scenario uncertainty, qualitative uncertainty, recognised ignorance)- Nature (epistemic and variability uncertainty)Note that scenario uncertainty may apply in at least two situations- When using multiple conceptual models to represent the effects of model structure uncertainty- When using alternative management scenarios to represent possible future outcomes

References:

Walker WE, Harremoes P, Rotmans J, Van der Sluijs JP, Van Asselt, MBA, Janssen P and Krayer von Krauss MP. Defining Uncertainty. A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. Integrated Assessment, 2003, 4(1), 5-17.

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.

Update of Parameters

Periodical or event based recalibration of the model generated by the assumption that the catchment behaviour, characterized by model parameters changes during flood events.

References:

Refsgaard, J. C., 1997. Validation and Intercomparison of Different Updating Procedures for Real-Time Forecasting. Nordic Hydrology 28:65-84.

Yang, X. and C. Michel, 2000. Flood Forecasting With a Watershed Model: A New Method of Parameter Updating. Hydrological Sciences Journal 45(4):537-546.

Verification of Code

Proper tests have to be conducted to document that the code solves the algorithms with a given level of accuracy. Furthermore the code must be checked for bugs.

References:

ISO 9000-3 (European Standard) "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"

Visualisation and Tabulation

Visualisation techniques and computer graphics can provide rapid and effective methods for checking the quality and consistency of data, confirming that data has been correctly input to the model, and comparing model and system outputs. They represent a minimum level of checking that should be performed. Simple plots of spatial and/or temporal variations can readily identify 'outliers' and anomalies. Plotting and over-plotting data from different sources on the same graph can highlight inconsistencies and shifts in relationships. Plotting indicators of model performance for different sites (e.g. Gauging stations) or sub-structures (e.g. model layers), or during model calibration can indicate specific problems and instabilities, and help provide an overview of model behaviour. Tabulated summaries (mean, standard deviation, maximum and minimum values) of data or model results from different sites can also help identify anomalies, and they can provide a basis for infilling bad or missing data values. However, they are not generally as useful as graphical methods. There are many generic types of plot that can be produced using standard spreadsheet and GIS packages, but database and modelling software may include procedures to generate specific plots automatically. In either case, statistical tests and procedures may also be performed, such as bad value (or outlier) identification, correlation and regression, curve-fitting, infilling of missing or erroneous values, and scaling from point to areal values. Some of these techniques are described separately.Among the most useful of visualisation plots are:- Cross Sections (through topography, geology, river channels, flood plains, etc)- Long Sections (showing bed, bank, floodplain and channel structure levels; and maybe flow rates and levels, pollutant inputs, etc along a watercourse – helping to identify discontinuities and relationships)- Mapping, Contouring and GIS (catchment boundaries, geology and soils, land use, process parameters, mean or extreme values of observed/modelled time-series such as water levels, rainfall, pollutant inputs, etc)- Time series plots (one or more inputs and/or observed or modelled outputs, instantaneous values or period accumulations – identifying gaps, constant periods, changes in decay rates, and ‘noise’ that could indicate one or more of infilling, malfunction, poor data or poor model convergence; overplotting time-series to identify consistency between sites)- Trends plots (event, monthly, annual, or cumulative values of discharge against rainfall or site A against Site B, etc)- A "Box-and-Whisker" plot can be useful for handling many data values. They allow people to explore data and to draw informal conclusions when two or more variables are present. It shows only certain statistics rather than all the data. Five-number summary is another name for the visual representations of the Box-and-Whisker plot. The five-number summary consists of the median, the quartiles, and the smallest and greatest values in the distribution. Immediate visuals of a Box-and-Whisker plot are the center, the spread, and the overall range of distributionGeographical Information Systems provide automated mapping and analyses such as contouring, spatial interpolation, and aggregation, and they are well suited to displaying, editing and processing remotely sensed topographical and land use data from satellites or airplanes. In particular, high resolution Digital Elevation data (2-5m horizontally and 0.2-0.5m vertically) can be used to define water divides, river routes, and catchment areas, providing hydrological rationale for any subsequent contouring, interpolation and aggregation of variables. The need to edit spatial data should be recognised – for example to correct:- Elevations that reflect tree or building heights- Land use misclassifications- Embanked and diverted riversMapping procedures are very useful in PR studies to identify patterns and errors in rainfall and pollution. Long sections are particularly useful in HD studies to identify changes or errors in river bed and surface levels – especially at controls such as weirs, bridges and locks – and also to assess the consistency of flow rates along a watercourse. Long sections are also useful in WQ and BI studies to relate the location of point pollution sources with mixing lengths, river vegetation and habitats. A number of other plots (Double mass curves, Rating Curves, Scatter Plots, Pumping tests) are described as separate methods.

References:

Chambers, J.; Cleveland, W.; Kleiner, B.; and Tukey, P. Graphical Methods for Data Analysis.

Belmont, CA: Wadsworth, Rykiel, E.J. 1996. Testing Ecological models: the meaning of validation, Ecological Modelling, 90, 229-244.

Sargent, R.G. 1984. A tutorial on verification and validation of simulation models. In: S. Sheppard, U. Pooch and D. Pegden (Eds), Proceedings of the 1984 Winter Simulation Conference, IEEE 84CH2098-2, pp. 115-122.

Tukey, J. W. "Box-and-Whisker Plots." §2C in Exploratory Data Analysis. Reading, MA: Addison-Wesley, pp. 39-43, 1977.

Zonation

Zonation is the discretisation of an area being modelled into regions, units, or zones of influence, within which a constant value for a variable or parameter is assumed. A region may be a geographical subarea of the entire area being modelled, e.g. part of an aquifer or a homogeneous zone of an estuary. A unit may be an element such as land use type, soil type, geological layer, stream type, habitat, or community subdivision that can be represented by a uniform value. A zone of influence may be the area over which a gauged value is applied, e.g. Thiessen polygons, formed by the perpendicular bisectors of lines connecting each or a number of gauge sites, and defining the area closest to each gauge.

References:

Abbott, M.B., Refsgaard, J.C. (1996). Distributed Hydrological Modelling. Water Science and Technology Library, Vol. 22, Kluwer Academic Publishers, 321 p.

Vieux, B.E. (2004). Distributed Hydrologic Modeling Using GIS, Water Science and Technology Library, Vol. 48. 294 p.