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Uncertainty Matters: Computer Models at the Science–Policy Interface

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Abstract The use of computer models offers a general and flexible framework that can help to deal with some of the complexities and difficulties associated with the development of water management plans as prescribed by the Water Framework Directive. However, despite the advantages modelling presents, the integration of information derived from models into policy is far away from being trivial or the norm. Part of the difficulties of this integration is rooted in the lack of confidence policy makers have on the incorporation of modelling information into policy formulation. In this paper we examine the reasons for this apparent lack of confidence and explore how some tools, presently in use, address this problem. We conclude that public confidence in models is highly dependent on the way uncertainties are addressed and suggest possible directions of action to improve the current situation. Four real case studies illustrate how computer models have been used in The Netherlands for carrying out management plans at regional and national scale. We suggest that the solution to integrate modelling information into policy formulation lies on both the modelling and the policy-making communities.

Key words water framework directive · integrated management · model uncertainty · model confidence · participatory modelling · science policy interface

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1 Introduction

The use of computer models in water management is receiving increasing attention, as a result of a new set of policies prescribed by the EU Water Framework Directive (WFD). These policies focus on a participatory approach of water management. They solicit the development of management plans that integrate knowledge provided by different scientific domains (i.e., ecological, physical and socio-economical aspects of water availability and demand) while collaborating with various stakeholders, policy makers and the public. As such, the implementation of the WFD presents policy makers with several new challenges. Under the WFD, policy makers are not only required to develop highly integrated water management strategies, but also they need to devise tools and methods that allow them to design and carry out such novel management approaches as fast and accurately as possible. It is here that computer models can play a pivotal role.

Computer models can provide a general and flexible framework to study how water and river basin systems behave and how these systems may react to different policy choices. They can also contribute to the involvement of citizens and other stakeholders, by allowing a range of 'what–if' scenarios to be tested simply and cheaply. Further on, coupled models can provide a means to understand the interactions of technological, environmental and human subsystems under various management strategies. However, despite significant progress towards the development and integration of computer models as a tool for policy formulation, their use is far away from being trivial or the norm.

To investigate how computer models can be used to advantage and support of WFD policies, the Harmoni-CA project (www.harmoni-ca.info) held a series of workshops where policy makers and modellers participated. The results of these workshops showed that part of the difficulties of incorporating computer models as a tool for policy formulation is rooted in the lack of confidence policy makers have in model information. Generally speaking, policy makers consider computer models as potentially unreliable tools. Being the ultimate responsible parties for the decisions, they fear that the incorporation of model information could mislead or bias the decision making process.

If computer models are to be used to support the participatory elements of the WFD, enhancing the confidence policy makers, and other stakeholders, have in the modeling process and its results is an essential issue. This paper constitutes a step towards this goal. It aims at opening a dialogue where modelling expectations, needs and possibilities can be unambiguously stated. We first examine in detail the reasons for the apparent lack of trust in using models for policy making. Then we investigate some of the current tools and initiatives that address these problems, going on to the central issue of how the confidence in model results can be improved. We present four study cases that illustrate real experiences in the recent history of the Dutch national water management sector, where computer models are used by policy makers and water managers to carry out decisions at national and regional level.

2 Problems Affecting Public Confidence in Models

One theme group of the Harmoni-CA Synthesis Workshop held in Osnabrück in October 2004, was tasked with investigating the issue of "improving the confidence of policy makers in the use of models in decision making". The group comprised both policy makers and modellers, who had a varied experience in developing and using models to aid the decision-making process. This experience was used initially, during a brainstorming exercise, to produce a list of all the reasons for this apparent lack of confidence. The outcomes of this exercise fell into one of two categories; agreed causes that were mentioned by both modellers and policy makers, and a couple of causes that were only raised by policy makers, and therefore represent a 'gap' in the interface between the two groups. These causes are summarised below.

2.1 Agreed Causes/Issues

The following were the issues mentioned by both groups:

- Policy makers do not understand models
- Lack of certainty or validation[1] of the models
- Restrictions in models
- Lack of integration of policy makers and modellers
- Modellers' behaviour
- Lack of stakeholder involvement in the whole modelling process.

There is a long history of the development and use of simulation models, going back to at least the 1970s, and it is clear that their use in decision-making will continue or increase as there is a need to understand and manage ever more complex systems. In spite of this, there was general agreement that there remains very poor integration of modelling in the decision process, combined with a lack of policy frameworks for involving all groups and stakeholders who have an interest in a particular problem or issue. Underlying all of this was poor communication between decision-makers and modellers. In particular, there was a need to de-mystify the scientific basis of any model, such that policy makers and other non-technical stakeholders could understand why it had been chosen. Indeed, there was a need to explain why it was an appropriate model to use in that situation. A key aspect of this apparent lack of integration, between the different positions, was that policy makers were not involved in specifying the model at the start of the project and agreeing that it was fit for purpose. For other stakeholders the situation was perceived to be even worse, having, if any, a minimal input, at any stage of the modelling process.

During the workshop, it was agreed that this situation mainly derived from a poor understanding of computer models, on the part of policy makers, and a lack of understanding of the use of models in the decision making process, on the part of model developers. Generally speaking, policy makers were not familiar with the modelling process; commonly they did not know what models do and what type of questions models could answer. Many policy makers used models as if they were a *black box*, i.e., a device that, operating in a way that is completely ignored, provides the desired output result. Under these circumstances the participation of policy makers in the modelling process was not encouraged and misinterpretations of modelling results were likely.

Conversely, there was a poor understanding on the part of model developers of the decision-making processes that policy makers have to manage, and the types of decisions they have to make. Greater clarity was needed in terms of the role of models and how their results were being used and interpreted. The underlying problem appeared to be a poor dialogue between the two groups, which affected all aspects of the modelling process. This

[1] The term validation is understood *sensu* Refsgaard and Henriksen, 2004

included issues such as how well the model had been shown to match reality, what its restrictions were, and even what language should be used to express these concepts to a wider audience. Modellers were sometimes viewed as poor team players, promoting and using their own models outside of the main decision-making process.

2.2 Specific Policy Maker Issues

The additional issues that were only raised by the policy makers provide a useful summary of the over-riding concerns:

- Changing models
- Predictions vs reality.

When it comes to discussing the meaning of model validation or certainty, then policy makers were keen to stress that they knew and accepted that prediction is not reality. What, however, was missing was more information on the uncertainty of any model result or outcome and how this arose from the limitations or assumptions of the models. A further compounding factor was that policy makers were unhappy with models changing through time, such that different outcomes could be produced for the same assumptions. Moreover, there were several models that could potentially be used to address specific questions. What policy makers really wanted was "one answer, one model please", allowing that the answer needed to be associated with a specific measure of uncertainty or confidence indicator.

3 Procedures/Models/Solutions that Address Some of these Issues

Having identified the problems and issues that appear to exist currently in the use of models in decision making, the workshop theme group then considered the likely actions or solutions that would be needed to improve the situation. Overall, it was agreed that improved communication should remove many of the problems. Whilst it is very unlikely that there will ever be only one unchanging model for each type of problem, more explicit treatment of model assumptions and uncertainty would appear to support the use of models by policy makers in their day-to-day working.

Thus, it was agreed that a more participatory approach to model development and use was required. Policy makers and other stakeholders needed to be involved in the design and development of models to ensure that the right questions or issues were being addressed. It was also suggested that modellers could undertake market research of policy needs to better tailor their models to end-users. In addition to greater involvement in the building of models, there was also a need to improve their output formats, again taking on board the views of other stakeholders. These improvements would need to be backed up with better communication, so that topics such as data needs, underlying science and model assumptions/limitations were understandable by all. A "lingua franca" was needed to facilitate the dialogue between the two communities.

Using their own knowledge and the information presented at the workshop, the theme group considered which models or tools currently exist, that may already incorporate some of the above solutions. Three tools were identified as providing many of the answers. Brief summaries of these tools are described below.

MULINO (Giupponi et al. 2004; Mysiak et al. 2005) is a decision support system (DSS) designed to identify, explore and solve problems in the water management arena. It is based on a multi-sectoral and integrated approach for the sustainable use of water resources. Its implementation combines socio-economic and environmental models with geographical information system (GIS) capabilities and a multi-criteria decision tool. MULINO offers a common approach to decision making, but at the same time it provides the flexibility needed to adapt to the specific objectives and constraints of particular decision problems. Its application comprises the European management policies and facilitates the implementation of the WFD.

Policy makers and modellers thought that MULINO presented several advantages over other modelling approaches. They all agreed that this tool could improve some of the communication problems that currently exist between modellers and policy makers. MULINO provides an environment that facilitates the agreement process among the different parties involved in a management problem, driving people to talk the same language, presenting modelling results in a clear and logical way and aiding the comparison of different policy scenarios. One of the disadvantages it presents is that it does not offer a comprehensive and exhaustive treatment of modelling uncertainty. It captures only those uncertainties associated with decision making, providing a poor treatment of those uncertainties that relate with the process of conceptualization of a managerial problem and those which cannot be conceptualized in terms of probability distributions.

TWO–Le (Castelli et al. 2004) is a decision support system (DSS) designed for planning and managing multipurpose reservoir networks. It aims at assisting water authorities in the design of management policies and plans for lakes and reservoirs and also at supporting the analysis of various policy scenarios. It distinguishes two levels of decision-making, one that considers decisions made at the planning level and the other at the managing level. In its formulation it adopts a Bayesian Belief Networks (BBN) approach of modelling.

The workshop participants agreed TWO–Le presented several characteristics that were favourable to improve model confidence. Its main advantage is that it allows a participatory process by encouraging different parties involved in the decision making to establish a common language of communication. It also supports negotiations and the exploration of different managerial alternatives. TWO–Le improves the treatment of modelling uncertainties with respect to other methods. However, similarly to MULINO, it restricts its attention to uncertainties associated with decision making as represented by conditional probabilities, leaving out consideration other types of uncertainty, such as those associated with model conceptualization.

Participatory modelling can take many forms (conceptual, practical, formal) and can serve many needs (Magnuszewski et al. 2004). However, the common purpose of this type of approach is to increase understanding of the complex socio-ecological systems across all levels and sectors of society. Recognising that traditional environmental management and assessment techniques were not producing satisfactory outcomes because of the omission of complex feedback loops and non-linearities, a new set of tools has been developed to facilitate the dialogue between “experts” and a range of other stakeholders. Deriving a common language or understanding of complex systems under increasing variability (e.g., climate change, globalisation) is therefore a fundamental characteristic of such techniques. Increasing use of systems analysis (such as mental mapping) is being used to allow all stakeholders to graphically show their understanding of how systems function, and where they see the various links and feedback loops. In this way, an agreed understanding of the system can be reached, which can then form the basis of more detailed regional sustainability models. Such participatory techniques establish both trust and new working relationships across society, and also contribute to new learning and adaptive management processes. Whatever tools or techniques are employed, a flexible learning process is needed, that can integrate research, policy and local experience and practice. Thus by involving all stakeholders in the research, differences and commonalities in the way in which problems are seen, handled and solved can be explicitly acknowledged, creating a better environment for understanding and consensus gaining.

Policy makers and modellers thought this was a challenging but transparent, logical approach, able to efficiently produce results. It also constitutes an educational tool able to teach about the modelling process and how models can be used. Both communities agreed that the main strength of this approach is that it makes the participation of the different parties involved in a management problem possible, allowing to incorporate a pluralism of perspectives into a model. Thus, this approach constitutes a step forward in the incorporation of uncertainties that emerge from the lack of consensus or the ambiguities associated with the interpretation of a particular management problem. However, it lacks an explicit treatment of other uncertainties associated with the modelling activity.

The above three modeling approaches, discussed at the synthesis workshop, are simply examples of current attempts to promote better dialogue between the scientific community and policy-makers, and which go a long way to addressing many of the concerns raised in the early part of the workshop. There are many similar approaches which have been successful at improving the formulation and testing of real-world problems, and in the case of participatory modelling in providing a means of capturing some of the uncertainty inherent in our framing and understanding of the world.

However, from this overall assessment, it was clear that the overriding remaining issue was the need for a more explicit and comprehensive statement of a model's assumptions and limitations and better information provided on the sensitivity and uncertainty inherent in the model outputs. The conclusion that lack of confidence in the use of models appears to derive from the poor communication of model uncertainties is developed in the rest of this paper.

4 Key Role of Uncertainty

As stated by the policy makers participating in the workshop, they generally expected information entering the policy-making process to be as objective and certain as possible. They considered that the presence of uncertainty is a critical constraint for decision making. They thus tended to avoid solutions that require dealing with uncertain information. Commonly, policy makers used models without taking into account modelling assumptions, and without examining how robust model conclusions were respect to variations in these assumptions, ignoring model uncertainties and predictive limitations. However, despite the tendency shown by the policy making community to avoid uncertainties, these are an intrinsic and, and sometimes, irreducible component of models.

During the synthesis workshop it was agreed upon between policy makers and the modelling community that dealing with uncertainty faces two challenges. Firstly, uncertainties in model outputs have to be analysed explicitly and comprehensively, and, secondly, they have to be communicated properly and transparently in order to serve as information of value to policy makers. As Petschel-Held (2003) puts it concisely: "A model is only as good as its uncertainty analysis; a model application in transdisciplinary research is only as good as the communication of these uncertainties."

Uncertainty constitutes a deficiency in the information used to build a model. As defined by Zimmermann (2000) "uncertainty implies that in certain situations a person does not dispose about information which quantitatively and qualitatively is appropriate to describe, prescribe or predict deterministically and numerically a system, its behaviour or other characteristics". These information deficits are caused by many different reasons (i.e., error in measurement, variability, intricacy, ignorance, value and belief system, ambiguity and conflicting knowledge) affecting the modeling process at different levels and manifesting in the input data, parameter values, model structure and framing (Brugnach and Pahl-Wostl 2006).

For the purpose of this paper, we grouped uncertainties in two categories: situational and fundamental. "Situational" refer to those uncertainties that, at least in principle, are reducible and assessable by standardised procedures. They are related to what we could know about a problem, if we had infinite time and resources (human and financial) to generate more knowledge or collect all the relevant information. These uncertainties are determined by the amount and quality of the data available and by the selection, utilisation or disposability of specific knowledge about a problem (e.g., model input data). There is a variety of sophisticated methods and techniques in the market to assess and quantify situational uncertainties. A few of these are briefly reviewed in the following section.

"Fundamental uncertainties" refer to those uncertainties that are persistent with respect to the problem under investigation. They are related to what we at most can know about a problem, irrespectively of how much data or information we add to describe it. A classic example from physics is Heisenberg's uncertainty principle, which puts fundamental limits to the accuracy in the description of microscopic systems. Uncertainties here appear as a consequence of the complex dynamics that govern systems, in which a multitude of processes – natural and societal – interact in a non-linear fashion, making predictions at long time scales virtually impossible. When modelling, fundamental uncertainties are derived mainly from: (1) the intricacy of the information used, (2) the impossibility to predict developments on the paradigms, values and preferences that dominate in a society at any future point in time, (3) the unknown future technical innovation and transformation processes that may have an impact on the system under investigation, and (4) the poor communication and lack of understanding between modellers and decision makers. However, in contrast to situational uncertainties, fundamental uncertainties in models are not captured by current uncertainty assessment methods. Therefore, a proposal to deal in particular with fundamental uncertainties is presented in Section 4.2.

As a prerequisite for a succeeding communication of uncertainties it is essential to stress the difference between situational and fundamental uncertainties. This is in particular important for models representing a complex reality and thus having a rather high level of integration as is the case for most models aimed at supporting the implementation of the WFD.

4.1 Methods to Assess Situational Uncertainties in Computer Models

Model construction implicitly involves the embedding of assumptions at many levels and the particular, subjective (although perhaps consensus mediated) beliefs of the modeller. Finally, these assumptions propagate through the model, carrying uncertainty into model output. It is the uncertainty associated with the output which provides information about the reliability of model predictions and limits the confidence in these predictions (Ravetz 1999). They therefore play a pivotal role in model evaluation and interpretation.

Numerous methods are currently used for assessing model uncertainty in computer models (see Katz 1999; Omlin and Reichert 1999; Campolongo et al. 2000; Kann and

Weyant 2000; for general review see Refsgaard et al. 2005). From the methods available, sensitivity analysis is a widely used and general approach to study model behaviour (Haefner 1997). As defined by Saltelli (2000), sensitivity analysis is the modelling activity that studies the relationship between information flowing in and out of the model. It aims to determine the rate of change in model output in response to variations in input factors (i.e., parameters or input data are varied; Katz 1999). The measure of a model's sensitivity indicates how much an output can vary relatively to the variations in these input factors. The methods of sensitivity analysis can be classified in three types: (1) Screening tests, that are used to identify in an efficient manner the most influential factors, (2) Local sensitivity analysis, that studies the effects of the variations in one input factor when the others are kept fixed, (3) Global sensitivity analysis, that studies the effects of varying all inputs factors simultaneously.

Uncertainty analysis constitutes another commonly used approach of uncertainty evaluation. It measures the uncertainty of models' results. This class of analysis is concerned with estimating the overall uncertainty of model output given the uncertainty associated with parameters or input data (Saltelli 2000). In other words, the uncertainty associated with the output represents what it is unknown about the system modelled. For example, a commonly used method, Monte Carlo uncertainty analysis (Saltelli 2000), is based on a random sampling of the entire input factor space (e.g., parameters, input data) and determines how uncertainty propagates through the model and affects model output. While applications of uncertainty and sensitivity analysis have commonly been used to study the effects of parameter and input data uncertainty, recent developments have expanded to investigate uncertainty in model structure (i.e., model form; e.g., Brugnach 2005). This type of analysis focuses in investigating how uncertainty due to lack of complete understanding in the scientific concepts that are embedded into the model affects a model's internal structure and its emergent behaviour (Brugnach 2005).

Scenario analysis is another approach to understand the effects of uncertainty. It is used to investigate how model results can be affected by scenarios that simulate different possible conditions (e.g., future climatic scenarios). This type of analysis is generally used when different assumptions about the future want to be explored. Another type of analysis is offered by multiple model simulation, which is a technique that is used to analyze the effects of structural uncertainty. This type of assessment is carried out by comparing alternative conceptual models and evaluating how the different problem conceptualizations affect model results. Finally, there are other approaches, such as peer review, stakeholder involvement, expert elicitation that use subjective opinions and expertise in order to evaluate model performance.

From these methods, there is no single one that can be considered general enough to be applicable to deal with all forms of uncertainty in computer models. Each method has different uses and applications (Saltelli 2000; Van der Sluijs et al. 2004) and it conveys uncertainty information differently. The selection of the method to use depends on the goals of the analysis, the characteristic of the model to be analyzed (e.g., modelling approach used to develop the model), and the aspects of uncertainty that need to be uncovered.

4.2 Proposals to Deal with Fundamental Uncertainties – The 'Uncertainty Agent'

An assessment of fundamental uncertainties depends to a certain extent on the values, paradigms and experiences of the person(s) conducting the assessment. As an agreed cause for a lack of public confidence in models the synthesis workshop participants identified a lack of stakeholder involvement in the modelling process thus arguing for strengthening the concept of participatory modelling. It is argued here that in view of partly value-driven estimations of fundamental uncertainties in integrated modelling exercises this concept is to be extended to a participatory uncertainty analysis.

Within such a two-sided participation process, where non-scientific experts and policy makers can introduce their perspectives in the scientific model development process and uncertainty analysis, a mutual learning process can take place. This leads to more transparent results than can be easier to accept. Not only with respect to the problem under investigation itself, but also in terms of an adjustment of the mind sets of both the model developers and the policy makers, on the notions and conceptions of modelling and uncertainty. A method particularly suited to support and push this participation process is scenario analysis. The objective of this method is not to forecast or predict the incidence of a certain event, but rather to foster insights into the spectrum of possible scenarios that are "coherent and plausible stories [...] about the possible co-evolutionary pathways of combined human and environmental systems" (Raskin et al. 2004). The power of this analysis lies in its ability to integrate quantitative analyses based on models and data and qualitative elements, where data are not available or impossible to collect and where processes, variables or indicators are not quantifiable and depend on value judgement. By incorporating different stakeholder perspectives on future development pathways of the system investigated, this method allows to transparently address fundamental uncertainties. It also facilitates generating shared knowledge on the fundamental limits of the predictive power of integrated models, thus helping to relativise the request of policy makers on 'one model, one answer, please' (see Section 2 in this paper).

However, succeeding communication in participatory processes is not a matter of course, in particular when it is about an issue as complex as the assessment of and the acquaintance with uncertainties. The proposal, therefore, is to create the position of an 'uncertainty agent', as an essential part of any large integrated project that supports the implementation of the WFD and has a designated modelling orientation. The uncertainty agent would be explicitly responsible for managing the communication of uncertainty-related aspects between the model and policy makers as part of the participation process. At the beginning of the research process the uncertainty agent would initiate the communication process by "interviewing" both the model makers and the involved policy makers. The model makers are requested to provide a preliminary scientific compilation of the types and sources of uncertainty considered most relevant for the modelling task at hand. Similarly, the policy makers are asked to comment on what they consider as crucial uncertainties with respect to the associated decision making process they are faced with. Beyond that, the policy makers should generally characterise which role uncertainties play in the decision making process, how they practically deal with them and, most importantly, what they expect from the model makers concerning the acquaintance with uncertainties in the model outputs. On the basis of a preparation of these information concerning agreements and disagreements, different perspectives or different mind sets, the uncertainty agent would confront model and policy makers with their respective views, e.g., within the framework of a dedicated common workshop. The overall objective of this dialogue would be to establish a common representational level and a project concept for dealing with uncertainties.

The major task of the uncertainty agent then would be to organise, manage and facilitate a communication process throughout the whole of the research process. Within this process the uncertainty agent mediates intermediary results of the scientific uncertainty analysis to the policy makers and feeds back their reaction on the influence of these results on the decision making process to the model makers. From this, a mutual leaning process might emerge leading to an assessment of uncertainties which integrates a scientifically sound uncertainty analysis with the constraints and dynamics of the decision making process.

Policy-relevant messages derived from modelling exercises, are those that reflect the inherent uncertainty of a result, thus providing stable guidance in the decision making process. Formulating these messages requires a highly integrative approach, when combining the results of the uncertainty analysis with the main conclusions from the modelling output. In order not to undermine this integration, it is important to stress that the uncertainty agent is conceived as a mediator and not as a person who generates or holds the specific knowledge on the uncertainty assessment. Ideally he/she would be a person coming from the research community but having also strong experiences in the policy arena, making it easier for him/her to establish a common language between the modellers and the policy makers. The task of the uncertainty agent could be complemented by an intelligent software system, such as an expert system, developed and trained in the participatory modelling and uncertainty assessment process. By the end of a project, such an uncertainty expert system could be an indispensable tool to support the adaptability of a model in changing application environments.

5 Case Studies

5.1 Background to Water Policy in The Netherlands

In The Netherlands, both policy making and water management pursued at national and regional scales is often supported by models. However, there is a clear difference in the interaction modellers establish with policy makers and with managers. This difference is mainly due to the fact that these two groups take into account different aspects of water issues. On one hand, policy makers generally operate at a national level and consider the generic aspects of water problems. They demand support to be translated at a high level of abstraction (e.g., total costs of strategies) and for the country as a whole. On the other hand, managers tend to consider more specific aspects of water issues. They tend to focus on actual and concrete problems which are often regional in scale. They require models to support the decision process on the best measures possible at the lowest price.

The following examples aim to analyze the interactions in which modellers, policy makers and water managers engage during the decision making process and to discuss the differences in expectations, requirements and possibilities about models of the two decision making communities. The examples illustrate real experiences in the recent history of the Dutch national water management sector, where computer models are used by policy makers and water managers to carry out decisions at national and regional level.

5.2 Case 1: DSS Supporting Policy Making at National Level

For more than 30 years, water management in The Netherlands has covered many aspects related to the distribution and use of water under different circumstances. To help deal with these water issues, one of the first ever model-chain (instrument) for integrated water management, Policy Analysis of Water Management for the Netherlands (PAWN; Rand Corporation 1981–1983), has been applied. This model includes, nationwide, surface water distribution and groundwater flow, and takes into account demands (cost-benefit) for agriculture, shipping, cooling water, flushing of salinated waters, and recreation. The model has evolved over the years, improving the way of defining scenarios, its computations, the interpretation of results and the dissemination for use in policy making. Over the three decades of model use, seven national policy documents on water policy have been supported by PAWN.

During the development and application of this model, policy makers and modellers hardly communicated with each other. This model was exclusively developed and run by modellers, who were also responsible for applying the model in the different case studies. Once the model was applied, modellers passed the outcome to experts on national water management issues to be interpreted and translated into conclusions that could be used for policy makers in the support of the national issues. Policy makers generally required simple and straightforward results (preferably 1-dimensional), that could be delivered fast and that reflected integrated and overall weighted measures. Since the experts on national water management issues had a deep background in both modelling and policy development, they were able to easily interpret and translate modelling results, bridging the communication gap that existed between modellers and policy makers.

In light of this situation, it is clear that even though policy makers are willing to use modelling information, they are not particularly interested in understanding models or the uncertainties associated with these models. They completely rely on experts on national water management issues to provide the information but do not actively participate in the modelling exercise. At the core of this situation lies the problem that policy development is already a complex process in its own right, driven by administrational procedures, regulations and political negotiation. Policy makers do not want to further increase this complexity by trying to understand what models do or to introduce further uncertainty. For example, a large part of national policy making occurs in so-called inter-department (multi-ministry) fora. At this level many organisations of stakeholders exist, such as the union of water boards, the inter-provincial board, the board of drinking water production companies and farmers that are affected by political measures. While all these boards are consulted during the policy making process, this process occurs far away from the modellers that support water management.

At the national level, models had also been extensively used to solve short-term water management problems that required urgent solutions (e.g., safety of dikes or seepage of salt ground water). Many of these issues arise from analysis by the experts on national water management issues and are discussed with policy makers who may decide the matter that needs to be worked out in detail. In that case, the issues are directed by the experts to modellers. The modelers are then responsible for analyzing the issue and producing appropriate modelling solutions to investigate it. Finally, the results from the modelling solutions are re-interpreted by the experts, and communicated back to the policy makers. Often, modelling exercises consist of running a complex chain of national models with many parameters and input data, and involve the taking of many decisions (e.g., what model to use, what parameter values, what input data values, etc.) that can influence the results of the model as well as their interpretation. For the most part, these decisions rely completely on the modeller's criteria and knowledge about the problem domain and do not include the policy maker's perspective on the issue. As in the previous example, the experts on national water management issues play a critical role in translating real world questions into modelling objectives and then informing the policy making process with interpretation of the modelling results.

5.3 Case 2: Need for Support for National Policy Making with a Strong Regional Impact

Drought and water shortage constitutes an important issue in The Netherlands ever since the long and hot summers of 1975 and 1976. Measures developed at national level for solving this problem have become more and more concrete and regionally focussed, generating the need to have model results in agreement with water management practice. To this end, activities on the validation of surface water and ground water models have been recently initiated (i.e., Netherlands Drought Study in ARCADIS Ruimte & Milieu et al. 2003). This process of validation, by consulting regional and local water managers, is not regulated by any specific laws; it simple originates from the need to have measures being accepted in the actual field of water management.

In this validation process, modellers communicated directly with regional water managers to discuss the role, values and importance of the inputs and outputs of the models. While not all water managers were familiar with modelling concepts, those that had some modelling background were open and eager to learn about their water system as represented by a model. They considered that a national model showing the water balance of their region as part of the entire surrounding areas, could give them additional information and could help them to better understand water distribution at national level. On the other hand, water managers without a background in modelling entirely focused on their specific field of expertise or responsibility, finding it difficult to take into account a broad picture of their operations and the consequences of being part of a larger water system. On the other side, this validation process gave modellers specific information from the local or regional water manager on particular water systems.

From this experience, it was clear that regional water managers were well aware that models were not the real world but a representation of it that could be used to gain insight about different aspects of the water system. However, when considering the actual effects of measures to be taken, this perception of models changed and even national models were considered to represent reality in exact terms. Associated with this change in understanding there also was a lack of acceptance of uncertainty and a need to reduce it. In this context, the validation process, between regional and national models, offered an opportunity where both managers and modellers could learn, reducing the uncertainty by increasing availability of information. By communicating model backgrounds and adapting new ideas from the regional water manager, there was increased acceptance of national water management scenarios.

5.4 Case 3: Supporting Stakeholder Participation for Supra-Regional Strategic Decision-Making

In the low country of The Netherlands, water management includes protection against flooding by rivers and the sea. To prevent river flooding in the long-term, a large project on defining possibilities for widening the riverbeds at cost-effective and physically effective places has been initiated by the national government. The process of public participation has been quite successful. It is determined by national laws (including an EIA, Environmental Impact Assessment, or MER in Dutch) prescribing the need of public participation in the decision process. It is based on the perception that in a crowded and heavily planned country as The Netherlands, changes in land-use and water management can only be established by the support of a large numbers of stakeholders that want to be involved in all stages of the decision process.

Model support has been essential to derive conclusions and acceptance. Utilizing a user-friendly decision support system planning kit (Kors 2004), all interest groups have been able to analyse the physical effectiveness of measures along the entire river branches of the major rivers in The Netherlands. This tool uses representative relations between measures and effects distributed along the river branches that have been computed by complex physical models. Using this tool, policy makers from provinces and water boards, and the various groups of stakeholders, have been able to understand the water system throughout the entire region, as well as looking outside their own area, and to participate in the decision process. Further on, policy makers as well as stakeholders have been able to experience uncertainty by generating different scenarios by themselves. By choosing a set of measures with different strengths, and by looking at the impact, they learned about the role of uncertainty in the future of their water system.

5.5 Case 4: Supporting Stakeholder Participation in Practical Water Management

In the eastern part of The Netherlands a plan to lower the river levels under extreme conditions has been developed. This plan is based on changing the position of the river dike to widen the riverbed at a narrow cross-section near Lent. The decision process, that eventually became a decision of the Minister, was supported by the use of computer models. This decision process was regulated by EIA and public participation was required. Local water managers were consulted in different phases of the process, from the first steps at the beginning until the semi final preparations of the decision documents.

In this case, contrary to what happened at the national level, modellers and water managers have interacted extensively. There have been open and fair discussions on model results, uncertainty aspects and possible uncertainty measures. Individuals as well as stakeholder organisations were able to express their concern on different issues and could participate during the entire modelling process. Comments from all the parties were officially reported in the documents.

Due to the prescribed public participation, water managers were required to be very specific on the use of model results. The public believed that models were truthful representations of reality (e.g., it was expected that the water levels predicted by the model happened in the real world under the circumstances described by the model), and as such, model outcomes could be directly integrated in decision making. During this modelling application only uncertainty associated with input data and parameter values was accounted for; fundamental uncertainties were ignored. Water managers accepted the existence of uncertainties, but expected that, despite their presence, model results could cope well with the problem at hand. They believed that sufficient measures could be taken within the limits of the available budget, or alternatively, that the incorporation of additional data (e.g., field measurements) could reduce the existing uncertainties improving modelling results.

5.6 Case Study Conclusions

In the case studies the integration of models into policy making was mainly determined by the characteristics of the problem to be addressed and by the type of interactions in which modellers and policy makers were engaged. In these cases it was observed that at the national level, as was expected, the process of public participation in policy making was not determined by the modelling activity. At this level modellers and decision makers acted as two independent communities; while the decision makers were the ones responsible for policy formulation, models and modellers had little influence in this process.

The use of complex national models depended entirely on experts on national water management issues, who having a background in both modelling and policy making, where able to translate modelling information into the policy arena. These experts were the ones that, by understanding the models and uncertainties associated with them, were able to judge model suitability to tackle a particular decision making problem. While relying completely on expert opinions, policy makers did not show interest in understanding what models did, they generally conceived models as black-box tools, ignoring the model's internal details, functioning and uncertainties. However, this interest in understanding models by decision-makers and stakeholders increased with the degree of practical use of the issues that were supported by the model.

At regional scales, the modelling activity played a more influential role for policy making. As the water management problems became more concrete and local, the expectations, needs and possibilities of models increased. The problems to be addressed became more specific and easier to relate with reality, facilitating the interaction between modellers and policy makers. The case studies showed that through a process of participation, modellers and managers engaged in open discussions about the characteristics of the real world problems and the potentialities and limitations of the models to represent such problems. This participatory process made it easier for modellers to elucidate what policy makers needed and expected from models, as well as how they dealt with risk and limiting information. On the other hand, it allowed managers to learn about the modelling activity and the uncertainties associated with model results, gaining better understanding of what models can do and what they can offer.

Despite the advances in understanding brought by participation, the issues of model uncertainty remained unresolved. Decision-makers still conceived uncertainty as an undesirable quality associated with input data that could be reduced by gathering more information. This restricted view makes them believe that with more data, models could be improved and better predictions could be obtained. However the presence of fundamental uncertainties makes this belief unattainable. Thus, if models are to become part of decision-making, a new conception of modelling is needed, one that embraces uncertainties as an integral and, sometimes, irreducible part of the modelling activity.

6 Conclusions

The implementation of current water and river basin management plans can be significantly improved with the aid of computer models. Models can be used as a means to investigate a range of scientific and managerial aspects concerning water issues while conforming to the expected timetables. However, despite their advantages, models do not play a preponderant role in current management practices. This is mainly due to the lack of confidence policy makers have in computer models, precluding the incorporation of modelling information as an integral part of the decision making process.

As a result of the Harmoni-CA Synthesis Workshop, policy makers and modellers agreed that underlying this lack of confidence in computer models there is a problem of poor communication between these two communities, a poor understanding of the role of models in the policy making process, a lack of stakeholder involvement and inappropriate management and communication of uncertainty. While some of the existing modelling approaches improve the communication, participation and transparency of the modelling process, the issue of uncertainty remains unresolved.

Both communities agreed that uncertainties in model outputs have to be analysed explicitly and comprehensively, and that they have to be communicated properly and transparently in order to provide information of value to policy makers. However, this does not only imply a one way process in which modelling uncertainties are delivered to decision makers, but it also suggests the need of modellers to become aware about the role of uncertainties in the decision processes into which they feed their knowledge.

In this context, dealing with uncertainties becomes a complex process, whose solution not only depends on modellers but also requires the active participation of the policy makers and other stakeholders, involving knowledge sharing and exchange between the policy making and modelling communities. To this end, we propose an "uncertainty agent" who takes the responsibility of managing and communicating the different uncertainty aspects among the various parties involved. It is the uncertainty agent, who through a participation process brings together the diverse perspectives of the scientific and decision making communities, identifying the various deficits and information gaps. However, the function of this agent is not to act as a simple transfer mechanism that passes relevant information from one community to the other, but rather it involves acting as a mediator. As such, s/he is able to facilitate a mutual learning process where solutions that adapt to the objectives and needs of the involved parties can be better found. This, not only leads to more transparent process of model development and use, but also makes easier the integration of modelling results with uncertainty analysis and communication to generate policy messages that are robust against uncertainty.

Finally, for this solution to be successful, we claim that a shift in attitude within both the modelling and policy-making communities is much needed. To modellers, this means making models more understandable and improving the measurement and communication of uncertainty and model limitations, promoting the use of models as communicating, learning and exploratory tools. For policy-makers, this means a need to view modelling not as a way of achieving certainty but as a device to wisely inform the public and scientific community in an uncertain world. In our view, the responsibility to integrate modelling information into policy formulation lies on both, the modelling and the policy-making communities, which together should set the objectives and standards of the modelling activity. It is here where the ideas of participatory uncertainty analysis can help.

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