Position Paper<sup>☆</sup>

## Modelling with stakeholders

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## ABSTRACT

Stakeholder engagement, collaboration, or participation, shared learning or fact-finding, have become buzz words and hardly any environmental assessment or modelling effort today can be presented without some kind of reference to stakeholders and their involvement in the process. This is clearly a positive development, but in far too many cases stakeholders have merely been paid lip service and their engagement has consequentially been quite nominal. Nevertheless, it is generally agreed that better decisions are implemented with less conflict and more success when they are driven by stakeholders, that is by those who will be bearing their consequences. Participatory modelling, with its various types and clones, has emerged as a powerful tool that can (a) enhance the stakeholders knowledge and understanding of a system and its dynamics under various conditions, as in collaborative learning, and (b) identify and clarify the impacts of solutions to a given problem, usually related to supporting decision making, policy, regulation or management. In this overview paper we first look at the different types of stakeholder modelling, and compare participatory modelling to other frameworks that involve stakeholder participation. Based on that and on the experience of the projects reported in this issue and elsewhere, we draw some lessons and generalisations. We conclude with an outline of some future directions.

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*“What theory and science is possible about a matter the conditions and circumstances of which are unknown and cannot be defined, especially when the strength of the acting forces cannot be ascertained? ... What science can there be in a matter in which, as in all practical matters, nothing can be defined and everything depends on innumerable conditions, the significance of which is determined at a particular moment which arrives no one knows when?”*  
Leo Tolstoy, War and Peace, Book 9, ch. 11

## 1. Introduction

Stakeholder engagement, collaboration, participation, shared learning and fact-finding have become buzz words in many management-oriented areas of science. Hardly any environmental assessment or modelling effort today can be presented without some kind of reference to stakeholders and their involvement in the

process. In the 1970s the US Army Corps of Engineers (ACE) pioneered with efforts based on stakeholder participation in environmental decision making and assessment (Wagner and Ortolando, 1975, 1976). Even earlier than that Forrester, when creating the system dynamics approach, sought to involve clients in the process of model construction. Forrester (1961, 1985, 1994) emphasised the need to access the mental database of managers in order to be able to construct system dynamics models of strategic problems in business. In the 1970s this role of client involvement in the implementation of model results was more broadly recognised (Greenberger et al., 1976) as models started to enter the policy making arena. Modellers started working with individual clients and interest groups in all sort of ways. Not coincidentally it was also in the 1970s when the so-called “Sunshine Laws” were adopted by the US federal and state governments, requiring meetings, decisions and records of the regulatory authorities to be made available to the public. In some states public meetings were mandated to discuss a variety of decisions, one major example being timber sales in the Northwest. It was also at that time that the ACE called for the broad participation of stakeholders.

For decades prior, scientists had been carrying out their studies among themselves, modellers analysed the systems that were of interest to them, and software developers produced algorithms and programs that they believed would do the best job. Indeed, they were the experts; they knew better how the systems work, and

<sup>☆</sup> Position papers aim to synthesise some key aspect of the knowledge platform for environmental modelling and software issues. The review process is twofold - a normal external review process followed by extensive review by EMS Board members. See the Editorial in Volume 21 (2006).

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tended not to question why somebody else should decide what was needed to solve important problems. Through the intervening years stakeholder involvement has become almost a “must”. This is clearly a positive development, but in far too many cases stakeholders have merely been paid lip service and their engagement has consequentially been quite nominal.

It is one thing to bring managers and clients into a joint process of problem solving, where the ultimate goal of optimising a firm’s performance, say, is a relatively simple one that can be shared by all the players. It is much harder to achieve success in natural resource management, however, when stakeholders may represent local, federal, private and public organisations, as well as individual citizens and interest groups, which have very different, oftentimes conflicting interests. Furthermore, in a company or an organisation the boundaries of the system are well known, while in natural resource management systems the definition of the spatial, social and ecological boundaries are all part of the problem. Nevertheless, it is generally agreed that better decisions are implemented with less conflict and more success when they are driven by stakeholders, that is by those who will be bearing their consequences. The bottom-up approach, when the stakeholders play a role in the decision-making process, offers a lot of promise, especially in democratic societies, where unpopular decisions are hard to implement in a top-bottom scheme of events, when all the decisions come from the governmental institutions.

It does not follow though that public involvement does necessarily or automatically lead to legitimacy and support of policies (Korfmaier, 2001). On the one hand the efficiency of the participatory process depends on social relations between the stakeholders, their ability to communicate and exchange information and knowledge, and the skills and methods that can assist them in doing that. On the other hand there is a clear need for technical, analytical and modelling tools and software that can be used in this process (Mendoza and Prabhu, 2006). Over the last decade progress has been made both on the social and technical aspects, and this thematic issue aims at presenting some of these achievements. Different groups of researchers have advanced in parallel, developing and applying specific methodologies, which are based on the same principles but focus on different parts of the process. While we have seen several recent reviews of participatory methods in decision making (e.g. Reed, 2008), in this overview paper we focus on participatory modelling. We first look at the different types of stakeholder modelling that we have encountered, and compare participatory modelling to other frameworks that involve stakeholder participation. Based on that and on the experience of the projects reported in this issue, we draw some lessons and generalisations. We conclude with an outline of some future directions.

## 2. Definitions and typologies

There has been a proliferation of various clones of stakeholder engagement in modelling, or, rather, of the use of modelling in support of a decision-making process that involves stakeholders. In many cases the differences are quite subtle and it may seem that various agencies or groups come up with a new term to serve as a recognised trademark for their efforts. In essence they tend to be doing more or less the same things. Some authors (Lynam et al., 2007; Daniell, 2008; Renger et al., 2008) have recently proposed literature reviews on participatory modelling: below is a brief overview of various types of stakeholder-based modelling, as well as some stakeholder processes that do not rely on modelling.

### 2.1. Types of stakeholder-based modelling

**Participatory modelling** (PM) is a rather generic term that does not seem to be associated with any particular group. At the

same time there are names that are quite closely connected to particular schools or researchers and serve as trademarks of these groups.

**Group Model Building** (GMB) is a method that originates from the Netherlands and later used by the Decision Techtronics Group (DTG) in Albany, New York (Andersen and Richardson, 1997; Richardson, Anderson, 1995; Andersen et al., 2006), mostly in business applications but also for natural resource management (Exter and Specht, 2003). It is based less on formal modelling and more on Causal Loop Diagrams and similar visual tools (Vennix, 1996). It may be taken to the next step using systems dynamics tools (DYNAMO, Stella, Vensim) or Delphi. It involves a group of people, stakeholders, in one or more sessions to build the conceptual model. A facilitator who has experience with the method helps the group to build the model, usually staying neutral of the content. The modelling is considered as a process of building mutual understanding, defining terms and notions, and sharing experiences. A GMB session can start with reading a concept learning history, or even an unsorted pile of interviews, facts and narratives. During and after the session the so-called ‘Learning History’ is extended and then prepared for further implementation in decision making.

**Mediated Modelling** (MM) is a trademark that was introduced by van den Belt (2004), who runs a company “Mediated Modelling Partners, LLC” (<http://www.mediated-modelling.com/>). MM is not very different from GMB, except it does focus primarily on environmental applications. It usually builds on system dynamics, that is Stella (Metcalf et al., 2010). The use of icon-based software increases the transparency of the process. The modelling process is used to translate individual viewpoints into a common language, which is an important element of any mediation effort. Individual stakeholders collectively guide the development of a dynamic model, linking their different viewpoints about the system into a coherent whole. The process assumes a quite intensive participation of stakeholders in the process and usually requires a high level of commitment.

**Companion Modelling** (CM) is the brand usually associated with a stakeholder process that involves a combination of agent-based models and role-playing games, introduced in the mid 1990s by researchers from CIRAD (France). They have advocated three major principles: construction of the model with stakeholders, transparency of the process, and adaptiveness of the process, with the model evolving as the problems change during the study. The fundamental objective was always to raise the awareness of the stakeholders (including scientists) of the variety of points of view and their consequences in terms of actions. Then outcomes are expected either in terms of social learning or technical or organisational innovation. This approach has been tested over the last ten years and several papers in this issue present different applications of it (Souchere et al., 2010; Campo et al., 2010; Anselme et al., 2010; Rouan et al., 2010; Simon and Etienne, 2010; Worrapihong et al., 2010; Lagabrielle et al., 2010; Naivinit et al., 2010; Vieira et al., 2010).

Yet another brand is called **Participatory Simulation** (PS), which originates from the systems dynamics group at MIT in the early 1960s. This was then advanced by Meadows with such models and simulation games as Fish Banks (Meadows, 1986), a quite famous fishery optimisation computer game and role-playing game. Later on classes of so-called “object-based” simulation activities were developed (Resnick and Wilensky, 1998; Wilensky and Stroup, 1999). This was supported by a modelling language and software, **StarLogo** (2009), that simplified formulating individual based models, running them and visualising results (Wilensky, 1997). While the MIT version of StarLogo became open source and started to focus on gaming applications and teaching simple object-oriented

programming to youths, NetLogo branched as a modelling package for agent-based modelling. It was subsequently supplemented with so-called HubNet, an open client-server architecture, which enables many users at the “Nodes” to control the behaviour of individual objects or agents and to view the aggregated results on a central computer known as the “Hub” (NetLogo, 2009). This new development in participatory simulations for resource management allows people to play games over the Internet, also supporting chats (Guyot and Shinichi, 2006). One advantage of this technology is that every decision and every interaction is registered for further analyses. However, as it is used at present, the modelling itself is not participatory as the settings and the rules of the games cannot be modified by the stakeholders.

Another approach known as **Shared Vision Planning** (SVP) is the trademark emanating from the US Army Corps of Engineers (ACE). The SVP approach became quite standard for much of the planning activities within the Corps. Earlier SVP models were also based on Stella, though more recently there has been a transition to Excel mostly because of the availability of Excel to large groups of stakeholders. SVP has been mostly developed in applied studies primarily within the ACE, when planning and regulatory issues in water management had to be resolved (USACE, 2005; Palmer, 1999; Palmer and Werick, 2004; Deli-Priscoli, 1995;). Consequently, most of the publications are Corps Reports and conference presentations, with hardly any peer reviewed papers available so far. Examples of applications include the National Drought Study (IWR, 1994), the Lake Ontario – St. Lawrence River study (IJC, 1999), the Apalachicola–Chattahoochee–Flint/Alabama–Coosa–Tallapoosa River basin study (Palmer, 1998) etc.

All of these techniques relate in part to the educational method known as **Collaborative Learning** (CL). It appeared in the late 1960s as an approach to teaching and learning that puts learners in groups to work together on problems, complete a task, or create a product (Mason, 1970; Goodsell et al., 1992). CL (2009) is based on the idea that learning is a naturally social act in which the participants communicate and through this communication learning occurs. Learning flourishes in a social environment, which helps in problem solving. Nonaka (1994) and other scholars have shown that an organisation “learns” through exchanges among its members facilitating the circulation of tacit and explicit knowledge. These principles are clearly now driving many participatory modelling activities.

We can see that some of the basic principles of public participation were introduced quite some time ago, and have undergone development over several decades. While some of the foci in these different approaches may differ, we may conclude that basically they are very similar, and their advocates would probably quite eagerly subscribe to some basic principles, which we review below.

There are other examples when stakeholder participation is crucial, while models, in a broader sense, may also be involved. Modelling itself in these applications is not considered as crucial.

## 2.2. Other stakeholder-based processes

**Social science experiment** (SSE) is a methodology used by economists, social scientists, and especially psychologists to undertake experiments in human perceptions and behaviour. In most cases they are based on surveys about various choices that people make. This helps test hypotheses on decision making. In some cases they use a hypothetical model of a system, around which the decision making is developed. In the field of environmental management this approach has been detailed by Ostrom et al. (1994). For example, Cardenas et al. (2000) conducted experiments with stakeholders to test the importance of the

environmental, social and cultural contexts. Stakeholders played a game where payoffs were generated from a simple model of individual efforts to collect firewood from local forests. Here the participants were not involved in the formulation of the model. The model was used to explore human behaviour, and not to make decisions or understand how particular environmental systems work. We are not aware of any examples of SSEs where stakeholders would have contributed to the definition of hypothesis to be tested, or the models and experiments that were used.

The importance of participatory studies has been recognised for quite a while (Wadsworth, 1998) and also developed under the umbrella of **Participatory Action Research** (PAR) approach. While there is much in common with PM there are three major differences. First, PAR does not necessarily involve any modelling component. Second, PAR is a bottom-up, community and stakeholder driven investigation, which is usually initiated by social activists to solve particular local problems (Kemmis and McTaggart, 1998). Most of the PM efforts, while intended to be bottom-up, are still usually initiated and driven by scientific studies or policy and governmental agendas. The goal and hope in PM is certainly to instigate more community driven studies and solutions, but the driving force and funding rarely come from the community itself. The third important difference is the level of integration that is achieved, and the complexity of models that can be afforded. As it is clear from the name, a major difference between PM and PAR is the use of models in PM. In action-research people learn by doing; they actually modify the real system and learn from these modifications. With models it is possible to test the scenarios, the innovations in a virtual world rather than in reality. Although models are always simplifications of reality and are never perfect, this may help avoid unexpected effects that sometimes happen in PAR.

**Participatory Decision Analysis** (PDA) is somewhat broader than PM. PM is always focused on modelling as the major tool for decision making. The model is built with stakeholder involvement and this shared process of construction becomes the backbone of the decision-making process. The decision, in a way, becomes a by-product of this process, it organically emanates from the shared experience of learning and understanding that occurs in the process of model building. In contrast, PDA does not require that modelling or any other type of co-learning is involved. A model may or may not be used, it can be some existing models that are simply referred to in the process, or it can be simply data or expert opinions that are presented.

The major similarity is that in both cases stakeholder participation is essential. Stakeholders are involved throughout the process. PDA uses its own tools, such as Multi-Criteria Decision Analysis (MCDA), Bayesian Belief Nets (BBNs), Vector Analytic Hierarchy Process and other techniques to combine the values for a given action and rank the sets of actions (Arnette et al., 2010).

The advantage of incorporating PM in the PDA is that stakeholders become engaged in the co-learning exercise, which helps to clarify and homogenise values among the various participants. While at the beginning stakeholders may have strong disagreements about the importance of particular features of the system and may have very opposing views on the priorities and desired outcomes, the PM process helps exchange information and build a common set of views and shared understanding about the system. This can help bring the values closer together and may simplify the ranking process.

There are many tools, which can help in the formalisation of knowledge. People can collectively draw maps, diagrams, logical frameworks, databases, etc. There are methods that focus on mental models, trying to elicit and present the ways different stakeholders see the problem (Becu et al., 2003; Mendoza and

Prabhu, 2006; Giordano et al., 2007; Lynam et al., 2007). Sometimes the mental models are further integrated into simulation models, sometimes not. In this paper and in the Thematic Issue we will focus on the models, which are built to run simulations. Among the tools, the most frequently used are:

### 2.3. Software and analytical tools

#### 2.3.1. System dynamics

Most of these appeared as an outgrowth of the systems dynamics approach of Jay Forrester, and his DYNAMO language. The main assumption here is that systems can be represented as a collection of stocks connected by flows, so material or energy accumulates in stocks and moves between them through flows. Stella was one of the first ones that captured worldwide recognition due to a very nice graphic user-friendly interface (GUI) and a fairly wise marketing program that particularly targeted students and university professors. A number of other software packages followed that are superior to Stella in many aspects. Other packages in this category are: Vensim, Powersim, Madonna, Simile and others. An expanded version of these are extendable tools, such as Extend, GoldSim, Simulink, and others. This software has many more icons than the stocks, flows and parameter operations of the Systems Dynamics tools. Whole sub-models or solvers for mathematical equations, such as partial differential equations, may be embedded into specially designed icons that later on become part of the toolbox for future applications. Clearly a major advantage is that modelling systems can be extended to include almost any processes (Metcalf et al., 2010). However there are always limitations. A major one is that, systems dynamics tools in most cases are not well suited for spatially explicit formalisation. Simile is probably the only one of those that can well handle maps and spatial transport. Alternatively, Stella local models can be embedded in more sophisticated software tools such as SME (Gaddis et al., 2010). The other generic problem is that the more the power built into these systems, the more difficult they are to learn and to use.

#### 2.3.2. Bayesian networks

A Bayesian network (BN, also known as Bayesian belief network) is a graphical model that represents a set of variables and their joint probability distribution. BNs represent patterns of probabilistic dependence, or in other words a BN defines relations between variables in terms of the conditional probabilities for each variable included in the network, and allows reasoning under the uncertainties that are associated with these probabilities (Borsuk, 2008). A BN can model situations that are characterised by inherent uncertainty, and can help to understand the statistical inference. Like in other models, one of the challenges when building a BN structure is in defining enough, but not too many, variables. Probabilities based on the best available knowledge – either model-based, data-based or qualitative expert opinion – populate the link between two connected variables. Software tools used in this case are Tools include Netica, Hugin, Analytica, DBLI, and others. BNs were used on many occasions for natural resources management (Raziyeh et al., 2009; Farmani et al., 2009; Mesbah et al., 2009; Ticehurst et al., 2007) and also in a participatory context (Henriksen et al., 2007; Castelletti and Soncini-Sessa, 2007; Lynam et al., 2010; Martinez-Santos et al., 2010). During the participatory processes stakeholders are requested to identify the variables and to weigh their influence on each other. Two major limitations of BNs are that they do not handle feedback nor represent temporal dynamics easily. Feedback can be treated by restarting the BN with new conditions, and time can be handled implicitly in various ways such as states being defined on different time scales, or by replicating variables to represent multiple points

in time and making the value at one time dependent on the value at another. Spatial disaggregation of the model means more complexity in that a separate BN component is developed for each spatial element and linked to the wider network.

#### 2.3.3. Fuzzy cognitive mapping

A Fuzzy Cognitive Map (FCM) consists of nodes (or concepts), which are the variables, with connections (or edges) between them that represent the causal relationships between the concepts. Each connection gets a weight (between 1 and 0) according to the strength of the causal relationship between the concepts in nodes. A relationship can be either positive (when growth in one concepts stimulates growth in the other one) or negative (when growth in one concepts inhibits growth in the other one). This graphical form can be represented in a mathematical form of a matrix that lists all the connections and a state vector made of the current weights of the concepts in the system. The next state of the system is then calculated by multiplying the vector by matrix. If iterated the system may equilibrate, presenting a new state. Comparing the new and initial weights of variables can tell whether the system increases or decreases their importance through the connections. FCM focuses on feedbacks within a system. They can help frame the discussions with stakeholders, whose expert opinions can be used to put together the initial maps (Özesmi and Özesmi, 2004; van Vliet et al., 2010). Kouwen et al. (2008) suggest that there is much promise in integrating cognitive mapping and environmental simulation models, using qualitative probabilistic networks such as BNs.

FCMapper is a free software package to process FCMs and calculate important metrics for them. It can be downloaded for free from <http://www.fcappers.net/>.

#### 2.3.4. Agent-based modelling

To model complex phenomena that involve human or institutional behaviour it is helpful to represent them as multi-agent systems (MAS) and use an Agent-Based Modelling (ABM) approach. MAS describe the observed world in terms of actors (agents) that are characterised by certain rules (behaviour) that depend on the state of the environment, the state of the agent and its spatial location. Each agent is represented as an independent computerised entity capable of acting locally in response to stimuli or to communicate with other agents. The applications are generally developed with an object-oriented language. Swarm (Minar et al., 1996) was one of the first software packages designed for ABM. Now tools like Repast, NetLogo, Mason or Cormas are more often used. These tools, which include spatial representation, simulation utilities for Monte-Carlo type methods, and links to other software (GIS, databases), are useful tools for the implementation of different social or ecological systems. Algorithms or structures are provided to implement the link between agents and their environment and routines are provided to organise societies of agents. During the participatory process stakeholders help to identify the actors involved in the decision-making process, the interactions among them and with their environment. For the last decade many scholars have considered a new implementation model for agent-based modelling. They implement them through role-playing games (Bousquet et al., 1999; Barreteau et al., 2007). The combination of computerised ABM and role-playing games can also be invoked (Souchere et al., 2010; Campo et al., 2010; Anselme et al., 2010; Rouan et al., 2010; Simon and Etienne, 2010; Worrappimphong et al., 2010; Lagabrielle et al., 2010).

There are also many examples when stakeholder participation is organised around other software tools, for example Excel. The advantage in this particular case is that Excel is more accessible to more stakeholders, since it is usually part of a standard PC



configuration. When spatial aspects are most important, the modelling can be entirely handled by a GIS package. ArcGIS would be the most popular software in this case.

### 3. The model and the stakeholders: the process rather than the product

#### 3.1. Objectives and type of participation

There is usually a mix of two main objectives that drive the participatory modelling process:

- increase and share knowledge and understanding of a system and its dynamics under various conditions, as in collaborative learning (Lynam et al., 2010; Souchere et al., 2010; Campo et al., 2010);
- identify and clarify the impacts of solutions to a given problem, usually related to supporting decision making, policy, regulation or management (Lagabrielle et al., 2010; Simon and Etienne, 2010; Anselme, 2010).

In some cases priorities get shifted toward one or the other objectives, though in most examples we see that both elements are important (Gaddis et al., 2010; Martinez-Santos et al., 2010; Metcalf et al., 2010; Worrapiumphong et al., 2010; Rouan et al., 2010). It should be noted, however, that both objectives can be successfully treated in a study. Often they are synergistic and at least complementary but they must be jointly perceived by the stakeholder group as important. One does not come simply as a by-product of the other. If the project is focused only on learning we should not expect that problem solving will come of its own accord, and vice versa (Ramsey, 2009).

Distinction should be made between PM used as an instrument of collective analysis and used as an instrument of promoting a solution-oriented process. Increasing the knowledge of individuals in the social context and favouring the acquisition of collective skills is considered as a process of social learning (Mason, 1970; Pahl-Whostl and Hare, 2004; Hare et al., 2006). This helps stakeholders to improve their understanding of the system complexity, of the feedbacks between natural resource dynamics and social behaviours, and also of the interactions between stakeholders who have different points of views and different power (Barreteau et al., 2007). This social learning in many cases works as a good entry point to the next steps that lead to a solution to a given problem or help to develop or test the acceptability of a policy. Instead of modifying the whole through the awareness of all, the problem is to modify the whole through the strategic intervention by some.

The different objectives will also dictate the type of stakeholder participation that would be more appropriate for the project. After Arnstein (1969) who developed a ladder of citizen participation, Pretty (1995) suggested the following types of participation:

- Passive participation, in which the objective is just to inform people;
- Extracting information from people for the scientist who needs data;
- Participation to support the decisions, in which stakeholders are used to promote and articulate the chosen decisions;
- Interactive participation, where stakeholders share the diagnostic and analytical methods and tools or results;
- Self organisation, where the lessons from the participatory process are transformed into decisions by the stakeholders themselves.

Lynam et al. (2007), later, narrows this down to three types of interaction with stakeholders:

- Extractive use, in which knowledge, values or preferences are synthesized by the extracting group and passed on as a diagnosis to a decision-making process;
- Co-learning, in which syntheses are developed jointly and the implications are passed to a decision-making process;
- Co-management, in which the participants perform the syntheses and include them in a joint decision-making process.

Note that the term “extracting” has a very different meaning in these two typologies. While Pretty talks about “extraction” of information from stakeholders, Lynam et al. are referring to the “extraction” of results from the modelling study for the decision-making process. However in both cases the stakeholders are not considered as parts of the decision-making process.

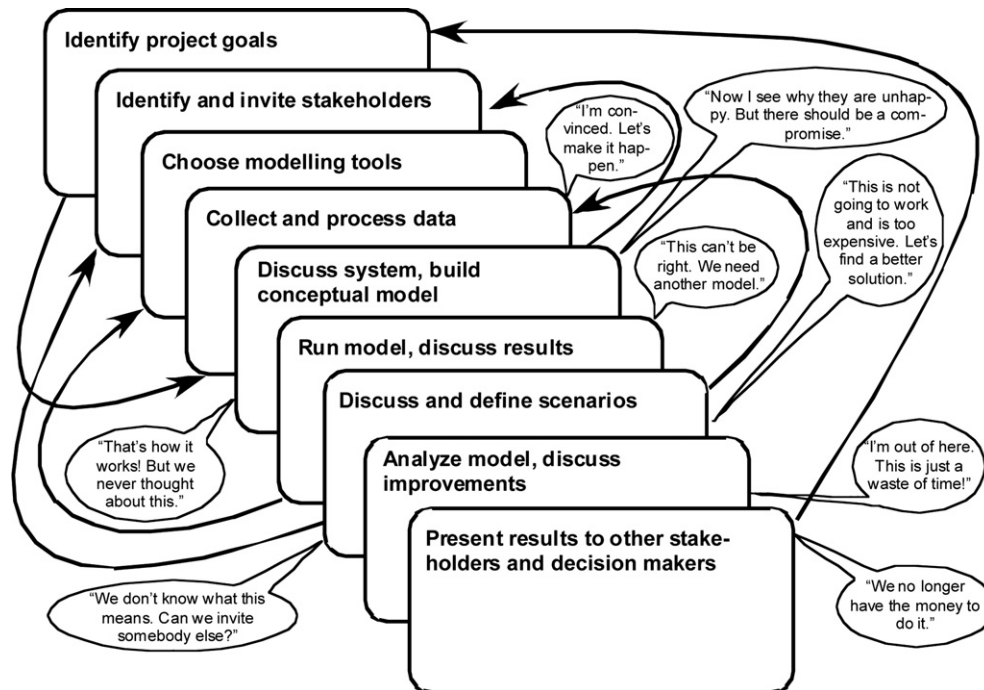
These points correspond to the different levels of application of modelling with stakeholders. Depending on the approaches the modelling will not be the same. In the following we distinguish the extractive use and co-construction. While all types of engagement are certainly appropriate, we think that a truly participatory effort would engage stakeholders in an interactive and iterative mode, where the flow of information is arranged in both directions: from the stakeholders to researchers/modellers and vice versa, from modellers back to stakeholders in a process of shared learning (co-learning).

There is an on-going debate between two opposing paradigms (Checkland, 1981; Funtowicz and Ravetz, 1994). Schematically, on the one hand the researchers following a positivist paradigm, try to discover the objective truth, even though they realise that there is no one single truth and no one solution. This knowledge is used to develop and deliver new technologies or new management rules. On the other hand the constructivist paradigm assumes that reality is socially constructed. “Based on their intentions and experience, people construct reality creatively with their language, labour and technology. Different groups do this in different ways, even if they live in the same environment. The same people change their reality during the course of time in order to adjust to changing circumstances” (Roling, 1996). Within this framework, any decision, particularly if collective, is context-dependent and should be seen as a stage at a given time in the continuous process of management of a complex system.

The emphasis has shifted from the static to the dynamic analysis, and from an individual to a collective level. The main role of interdisciplinary research teams, including natural and social scientists, should be to understand and strengthen the collective decision-making processes through communication platforms. Different stakeholders, including scientists, should work out a common vision on natural resource management (NRM). Based on this vision, appropriate indicators, shared monitoring procedures, information systems and concrete alternatives for action could be agreed upon. The role of scientists, biophysical and socio-economic, is then to feed such communication platforms with relevant and objective knowledge, and to propose ways of comparing, assessing and implementing the concrete NRM options that were decided collectively.

#### 3.2. Participatory modelling principles

With all the diversity of social and environmental conditions, it is hardly possible to come up with a generalised PM strategy. However some of the basic steps and elements seem to be present in all case studies and are shown in Fig. 1. Below is a list of important principles, which most of the successful PM efforts share.



**Fig. 1.** Different stages of a participatory modelling process. We have added the arbitrary loops back and forth, and have put these stages on cards to show that they can be shuffled at any moment. There is no particular order in how the process proceeds, and we may need to go back again and again, or we can jump several steps forward if the goals of the study are already achieved and management decisions are agreed upon. While the order is uncertain the major components of the process seem to be quite generic.

**Keep it flexible and make the most of the process.** There are plenty of useful models and algorithms that could be helpful in NRM. But stakeholders come with different perceptions and vested interests, different attitudes, varying levels of expertise and training, and different expectations. They may come with their own tools and models (including mental models), which may be hard to synchronise. They may be reluctant to spend much time on the project, especially when they are forced into a predefined procedure and tool set, especially if the tools and models come as pre-fabricated obscure black boxes that they cannot understand and appreciate (Ramsey, 2009). Most importantly, they expect to be part of the process from the very beginning, having a say in the goals of the study, which they certainly are in a better position to define, but also in the choice of methods, models and scenarios, and the scope of the study. In many cases this participation in the study becomes the most important and fruitful part of the project. Through joint research of the systems and co-learning, stakeholders arrive at a common understanding that can lead to conflict resolution (Susskind et al., 1999). The process of the study becomes even more important than the resulting model or method. As with other participatory methods, we are trying to build more equity and confidence in a heterogeneous group of people by providing a framework to share knowledge, cultural and traditional principles, access to power and status, ability to communicate and interact.

**It is open in time and space.** Environmental systems are open, which means that they constantly evolve and exchange information and material with the outside world. In any event the decision-making process in NRM is rarely closed in time. There are few decisions that are taken once and for all. Even before a study ends, and certainly before construction is finished or management practices are in place, there are likely changes to occur. These may be exogenous to the system (climate change, new policies) or endogenous (new data about the system, new players, new priorities). In NRM there is a strong human component that is always characterised by changing

values and priorities, and, consequently, changing interests in implementing certain management decisions. This requires modifications of the project, improvements in the design, adaptive management, adaptive modelling and adaptive decision making.

**Societal and scientific openness, transparency of methods and models.** Traditional science is not geared toward on-going collaborative research, that is open for the participation of multiple, perhaps unsolicited, players, including both scientists and stakeholders. If we want stakeholders to use our models, if we want the right decisions to be made to help resolve conflict and minimise environmental damage, we need to learn to work with stakeholders throughout the whole project, and to provide tools that they require, they choose, and they are willing to use. We may not necessarily know what these tools are going to be and whether we already have them or not. We argue that it is the decision-making process itself that needs to be collaborative, and that in this process all sorts of models will be needed. The existing models need to be tested, wrapped, documented, and archived in such a way that would make them available if stakeholders require them, and the models should be kept open so that they can be easily modified if such modifications are needed. Software architecture, not always sophisticated, is required that would allow flexible linkage between existing models and data sets of varying complexity, and that would allow extensions, and modifications of these models (Voinov et al., 2008a,b). Also required are tools for conceptual, scoping modelling and learning environments to engage stakeholders in such open-ended community research projects.

**Go in circles and branch out.** As with the regular modelling process as documented by Jakeman et al. (2006) and illustrated by Welsh (2008) and Robson (2008), and even more necessarily, a PM project iteratively loops through various phases many times. We should be prepared for unexpected changes in goals and priorities. Stakeholder motivation is an important factor in the success of the project, and we do not want to demotivate stakeholders by forcing them into a predefined protocol or procedure.

**Different kind of uncertainty.** In social systems, uncertainty has to be treated differently. The formal indices are based on a fixed model structure, which is already subjective. In PM the model is always evolving. As we modify the model structure the measures of uncertainty also change. As we switch from one knowledge or data set to another uncertainty indices change again. In participatory studies we find that uncertainty becomes a discussion point mostly based on perceptions and feelings. (“Do you believe in climate change?”) In decision-making, perception of uncertainty becomes more important than the actual uncertainty of our data, methods and models (Mysiak et al., 2008).

**Untraditional metrics of success.** The stakeholder process creates new criteria for model quality and applicability. While good practice of modelling (Jakeman et al., 2006) considers model ‘validation’ as an important element of model building, in a stakeholder process models tend to get a somewhat different meaning, since they are less important as a product in themselves. Instead a model becomes useful as long as it helps solve the particular problem that the stakeholder group is dealing with. In some cases the model may have gleaming flaws in terms of the conventional model calibration – validation – verification process, yet will still be useful for stakeholders to reach a consensus and to make the decision. Refsgaard et al. (2007) stress the importance of model evaluation in the context of uncertainties during the process, not only at the end.

We have also summarised these principles in Table 1.

#### 4. Lessons learned

We consider two categories of lessons drawn from various experiences conducted over the last decade: the lessons on the interactions among actors involved in the modelling process (social lessons) and the methodological modelling lessons.

##### 4.1. Social lessons

###### 4.1.1. Problem setting, who initiates and drives the process and how?

Dietz et al. (2003) consider the following groups in a PM process: the scientists, the officials and other interested parties. Usually the PM process is initiated by managers or researchers from a governmental agency or university. They drive the process in the beginning, and the first challenge usually is engage the right stakeholders in the process as quickly as possible. Local decision makers, or citizen activists may also play a role, but in most cases funding is sought from the government. In the United States, most PM activities are initiated by governmental bodies (Duram and Brown, 1999). In this issue there are cases where initial interactions were between scientists and officials (Anselme et al., 2010; Rouan et al., 2010), and other interested parties were invited later

on. In other cases, the process started from an interaction between scientists and interested parties (Worrapimphong et al., 2010; Simon and Etienne, 2010) and the officials were brought in at a later stage. Finally, in most cases scientists, officials and interested parties worked together from the very beginning (Gaddis et al., 2010; Campo et al., 2010; Souchere et al., 2010; Ticehurst et al., 2007; Lagabrielle et al., 2010).

Education of the community about natural resource management issues and the impact of decisions on the community is often a good first step. This can be accomplished through the media, town hall meetings, or volunteer and community-oriented programs. The possibility of new regulation catches the attention of the public and people become more willing to participate in the study, especially if there is a clear monetary implication (new taxes or fines). In other cases, interest from some stakeholders may only arise after a policy change that directly impacts them.

Stakeholders can be engaged in the form of knowledge provision, model selection and development, data collection and integration, scenario development, interpretation of results, and development of policy alternatives. It is generally recognised that engaging participants in as many of these phases as possible and as early as possible – beginning with setting the goals for the project – drastically improves the value of the resulting model in terms of its usefulness to decision makers, its educational potential for the public, and its credibility within the community (Korfmacher, 2001; Beirele and Cayford, 2002; Reed, 2008).

The beginning of the process is not the same for all actors. Usually only the scientist is aware of the possible uses of models. For many stakeholders this can be the first time they learn about models, and it may be difficult for them to feel fully engaged and comfortable with the process. This is less a problem if the objective is the extractive use than in the case of co-construction. One way to start the process is to show previous applications of models in similar contexts. It is always helpful to start building a conceptual model with stakeholders. Mind mapping exercises, participatory workshops with boxes and arrows, engaging stakeholders in role-playing games (Campo et al., 2010; Naivinit et al., 2010; Souchere et al., 2010) – all these are good tools to initiate the process. Another way is to propose a preliminary model, created previously by the scientists. Stakeholders can then propose modifications and start questioning the draft model. This second approach is often less time consuming, but the former method corresponds better to the genuine co-construction approach. In any case it is important to consider an iterative process to allow and encourage modifications, and changes to the model.

Another solution is to involve stakeholders in the monitoring process before commencing the modelling, raising the awareness of the problem at stake. Establishment of a community-based monitoring effort can be a particularly effective entry point to a community that is ready to ‘act’ on a perceived problem and is not satisfied with more meetings and discussion. Monitoring by citizens in particular provides other benefits to the research process. In many cases, they live close to monitoring sites or have access to private property such that more frequent and/or more complete monitoring can take place at significantly less cost than researchers could complete independently. Citizens also gain benefits by becoming more familiar with their study area, which is an educational opportunity that may be shared with other community members. When stakeholders see how samples are taken, or, ideally, take part in some of the monitoring programs, they bond with the researchers and become better partners in future research and decision support efforts (Gaddis et al., 2010).

A critical step, early in the participatory modelling process, is the development of research questions and goals of the process. The questions identified should be answerable given the time and

**Table 1**  
Some generic principles of good participatory modelling.

Keep it flexible and focus on the process rather than the product.
Environmental systems are open in time and space: make the process that deals with them also open and evolving. Promote adaptive management, adaptive modelling and adaptive decision making
Maintain societal and scientific openness, and transparency of methods and models. Rely on collaborative research, and open source models
Mind the people. Always be aware of social and group dynamics, special interests, power and hierarchies
Facilitate and encourage learning – learn from each other and the process
Go in circles and branch out – go back, reiterate, refine
Accept a different kind of uncertainty – be certain about uncertainty
Accept untraditional metrics of success – group validation and verification

funding available to the process. In addition, it is important that all stakeholders agree on the goals of the process such that a clear research direction is embraced by the entire group before detailed modelling begins. The goals of the study direct the choice of the stakeholders, and, later, the decision about the modelling tools that are to be used. However, it is also a ‘chicken and egg’ issue, since the stakeholders then can redefine the goals. This is why it is crucial to organise the participatory modelling process as an adaptive one, to be ready to redefine the goals and to adjust the models and methods used. At the same time this resembles very much the regular modelling process that iteratively loops through certain phases many times (Jakeman et al., 2006; Forrester, 1994).

#### 4.1.2. Stakeholder involvement – who, when, how?

Selection of stakeholders for a participatory process is a difficult issue. Regardless of the method used to solicit stakeholder involvement, every attempt should be made to involve a diverse group of stakeholders that represent a variety of interests. This adds to the public acceptance and respect of the results of the analysis. If a process is perceived to be exclusive, results may be rejected by key members of the stakeholder and decision-making community. When less organised stakeholder groups do not actively participate, information about their opinions should be obtained through other means such as public meetings, outreach or surveys (Korfmaier, 2001).

Different dimensions should be taken into account. The selected persons should represent a given category of stakeholders playing an important role. These people may belong to formal groups (associations, unions, lobbies, etc.) playing an official role, or can represent groups identified through typologies made by the scientists. The number of people invited can vary but in most case studies to date there have not been more than 30 or so participants. In a co-construction process it is difficult to engage many people. This number could be greater in extractive use of participation. The process of invitation needs special care. The actor (individual or collective) who invites the stakeholders should have certain legitimacy. The stakeholders are likely to project their perception of the inviter onto the process at stake, which will influence their commitment and activity. This can be modified later on during the process but the first impression and initiation may have a crucial role and may be hard to change at later stages. In some cases scientists are perceived as “neutral”, while in other cases they may be more perceived as linked to the governmental policy makers.

#### 4.1.3. Stakeholder organisation – workshops vs. permanent engagement, work groups or all

Depending upon the type of participatory modelling, the goals, the funding level and the time constraints of the project, stakeholders may be enlisted to participate in a variety of ways. In some projects stakeholders are sought out for their known ‘stake’ in a problem or decision and invited to join a working group. In other cases involvement in the working group may be open to any member of the public, and the project starts with a public announcement in mass media (Gaddis et al., 2007).

Never underestimate the “luck factor”. Just one or two stakeholders that choose to take an obstructionist position can damage the process. Likewise, several committed and active stakeholders can significantly enhance the effort. This raises the problem of the social context.

Intuitively transparency is a very important factor and one would advocate that maximum transparency should be an objective. However this objective does not imply that every stakeholder participates in each step of the process. Collaborative decision making can be achieved in different ways. Some scholars (working on what they call soft systems (Checkland, 1981)) favour dialogue

among stakeholders and state that the quality of the process and the potential decisions are very much determined by the quality of the dialogue. It is important to let people exchange their points of view, and that can influence them and lead to a shared understanding. Other scholars develop the critical learning system approach (Ulrich, 1987). For them it is more important to take into account the social system in which stakeholders are embedded.

The social context and social values of each group are certainly of great importance. The stakeholders engaged in the process are not in a symmetric position. They have different roles, different interests, different power levels and relationships, and the dialogue will not always benefit all stakeholders. They may have had contacts in the past, and they usually have different perceptions of each other. This social context has to be analysed and the process adjusted accordingly to empower the weak groups before the collective dialogue is started. Besides the facilitator is not always neutral (Barnaud et al., 2008). In some cases stakeholders should be placed in different groups because they would not express themselves freely in the presence of some others. Later the results can be communicated between groups, not necessarily identifying the sources of information. In other cases it may be important to form groups, which will work on different sub-models based on the different expertise that stakeholders bring. In some cases it is important to have everybody in the same group from the beginning. In the case of the co-construction process, time is a major factor to be taken into account. The process is iterative and the pace of the process depends on the social interactions among the stakeholders.

Using the web and establishing a prominent presence of the project on the Internet can substantially increase transparency and help engage more stakeholders (Voinov and Costanza, 1999). However, again, stakeholders come with varying computer skills, and relying too much on web interfaces can put certain groups or individuals at a disadvantage. Providing various levels of access to the information on the web can be helpful in this case.

#### 4.1.4. Role of scientists in the process

In PM process the scientist often plays many roles. Renger et al. (2008) consider five roles: facilitator, modeller, process coach, recorder and gate keeper. The objectivity of the scientists depends on the role they are playing. As modeller, the scientist makes sure that the scientific components of the model adhere to standard scientific practice and objectivity. This criterion is essential in order for the model to maintain credibility among decision makers, scientists, stakeholders and the public. Thus, while participants may determine the questions that the model should answer and may supply key model parameters and processes, the structure of the model must be scientifically sound and defensible. However in some cases scientific accuracy and rigour may be compromised for the sake of communication of ideas and achievement of results. Scientists should be clear about the assumptions and uncertainties. It is not warranted to give up on the project, simply admitting that there is not enough data or too much uncertainty. Stakeholders usually understand that even a conceptual or imprecise model is better than no model at all.

Furthermore, scientists as facilitators of a participatory modelling exercise must be trusted by the stakeholder community as being objective and impartial, and therefore should not themselves be direct stakeholders. Sometimes this is difficult to achieve. When governmental or non-governmental agencies act as facilitators of a collective process, they have their own stakes. In this regard, facilitation by scientists or outside consultants, if established as a neutral party, can reduce the incorporation of stakeholder biases into the scientific components of the model. However it may be hard to maintain neutrality, especially when scientific knowledge is



compromised by certain stakeholders, or when scientists develop their own understanding and viewpoints about the system and its future trends. In certain cases it becomes impossible to maintain neutrality and external facilitation may be the only way out.

In any case it is essential that stakeholders trust the facilitators and scientists, and a certain track record in the local area and perhaps even recognition of researchers by the local stakeholders based on past research or involvement can be helpful. An additional problem is the risk of delegitimisation and overlegitimation emphasised by *Korfmacher (2001)*. On the one hand the involvement of non-experts could cast doubt upon the reliability of model results. On the other hand decision makers may place too much confidence in the results of models, which are compromises between different points of views.

#### 4.1.5. *How to deal with surprise and conflict?*

In some cases, stakeholders may have historical disagreements with one another. One purpose of the PM process is to provide a neutral platform upon which disputing parties can contribute and gain information. However, it is important to watch for such historic conflicts and external issues that may overshadow the whole process. In addition, we have found that when the outcome of a modelling exercise is binding, such as in the development of Total Maximum Daily Loads (TMDL) of pollutants, parties may be more engaged but also defensive if they perceive that the process will result in a negative impact on them or their constituents. For example, point source polluters may look for ways to hold up a TMDL process in order to delay a load reduction decision. These sources of contention may be masked as scientific dissent when they are actually political. When conflict within the group becomes unmanageable, it is important to set out rules for discussion and in some cases involve a professional facilitator. In most cases the PM process helps to identify the vested interests that may be involved and lays the ground for consensus building (*Metcalfe et al., 2010*). It is crucial that the co-learning brings the stakeholders to a common level of understanding of how the system works and creates a level playing field for discussions.

## 4.2. *Lessons on the modelling methodology*

### 4.2.1. *Who chooses the modelling tools and how?*

Selecting the appropriate modelling tool is one of the most important phases of any modelling exercise. Model selection should be driven by the goals of the participants, the availability of data, the project deadlines and funding limitations, rather than by the scientists' preferred modelling platform and methodology. It is important to maintain 'model neutrality' and ideally, the choice of modelling tools should happen with the stakeholders after the goals are decided and after surveying the available tools and selecting the ones that are most appropriate (*Aquino (d') et al., 2002*). In reality, in far too many cases the scientists are inclined to influence the choice in favour of the tools that they are most familiar and comfortable with. The hope is that with the development of specialised participatory toolboxes and frameworks that offer easy access to a variety of integrated tools, we will see less dependence on previous experience of scientists involved in projects.

Pretty much in all examples treated in this issue, the modelling paradigms were a given in the stakeholder process. Still after that, the role of stakeholders can be different: models can be built collectively from scratch with the stakeholders or the group may start from models previously developed and proposed by the scientists (*Renger et al., 2008*).

In choosing the right tools for a PM exercise we might want to keep in mind the following. To be useful in a participatory framework models need to be transparent and flexible enough to change

in response to the needs of the group. In some cases tools as simple as MS Excel can be the right choice. Process based models help determine the mechanisms and underlying driving forces of patterns and have a higher educational and co-learning potential; however, they may become overly complex especially when the spatial structure of an ecosystem also has to be considered. Alternatively, Geographic Information Systems (GIS) explicitly model the spatial connectivity and landscape patterns present in a study area, but are weak in their ability to simulate a system's behaviour over time (*Westervelt, 2001; Lagabrielle et al., 2010*). Model complexity must be dictated by the questions posed by the stakeholder group as well as available data and information. Models that are too simple are less precise, but a model that is too complex can lose transparency and will be more difficult to communicate to the stakeholder group. Too many detail can also obscure the dominant system behaviour that is important to capture. In many cases a simple model that can be well communicated and explained is more useful than a complex model that has narrow applicability, high costs of data, and more uncertainty. In addition, selection of a complex model for which there is little data for model development and calibration may not be scientifically sound. It may also be more difficult to communicate to all stakeholders.

### 4.2.2. *Types of data and knowledge*

The knowledge, data, and priorities of stakeholders should have a real, not just cursory, impact on model development both in terms of selecting a modelling platform and in setting model assumptions and parameters. Stakeholders often contribute existing data to a research process or actively participate in the collection of new data. Some stakeholders, particularly from government agencies, may have access to data that is otherwise unavailable to the public due to privacy restrictions or confidentiality agreements. This data can often be provided in aggregated form to protect privacy concerns or if permission is granted from private citizens. In addition, some stakeholders are aware of data sources that are more specific to the study area such as locally collected climatic data.

The PM approach is based on the assumption that those who live and work in a system may be better informed about its processes and may have observed phenomena that would not be captured by scientists. Stakeholders can also be very helpful in identifying whether there are environmental or human-dominated processes that have been neglected in the model structure. They can also verify basic assumptions about the dynamics, history and patterns of both the natural and socio-economic systems. Anecdotal evidence may be the only source of assumptions about human behaviour in the study area, many of which are important inputs to a simulation model (e.g. frequency of fertiliser application). This type of knowledge when combined with technical knowledge of processes is critical for identifying new and more appropriate solutions to environmental problems (*Webler and Tuler, 1999; Gough and Darier, 2003*). The PM process serves to integrate all types of knowledge (empirical, technical and scientific) from a variety of disciplines and sources.

### 4.2.3. *The role of the model*

Giving stakeholders the opportunity to contribute and challenge model assumptions before results are reported also creates a sense of ownership of the process that makes results more difficult to reject in the future. This can only occur, however, if the models developed are transparent and well understood by the public or stakeholder group (*Korfmacher, 2001*). In some cases, it can reduce conflict between stakeholders, since model assumptions are often less controversial than model results (*Gaddis et al., 2010*).

Transparency is not only critical to gaining trust among stakeholders and establishing model credibility with decision makers, but is also key to the educational goals often associated with participatory modelling. The model developed should be relatively easy to use and update after the researchers have moved on. This requires excellent documentation and a good user interface. If non-scientists cannot understand or use the model, it will not be applied by local decision makers to solve real problems.

The modelling process should be flexible and adjustable to accommodate new knowledge and understanding that comes from the stakeholder workshops. This requires that models be modular, robust and hierarchical to make sure that changes in components do not crash the whole system. Simple models are easier to communicate and explain and understand, which makes them more useful than a complex models that have narrow applicability, high costs of data, and more uncertainty.

#### 4.2.4. *Dealing with uncertainty*

Many environmental questions, especially those that incorporate socio-economic processes, require analysis of complex systems. As problem complexity increases, model results become less certain. Understanding scientific uncertainty is critically linked to the expectations of real world results associated with decisions made as a result of the modelling process. This issue is best communicated through direct participation in the modelling process itself.

Stakeholders that participated in the model building activities develop trust in the model and are less likely to question the reliability of the results. Primarily that is because they know all the model assumptions, know the extent of model reliability and know that the model incorporated the best available knowledge and data, and understand that there will always be some uncertainty in the model results.

The validation of these models is a difficult task because they mix different epistemological references (Becker et al., 2005). Part of the model which represents the natural and the biophysical dynamics may be validated with traditional methods. The epistemological stance in this case is: “a true statement is the one that corresponds to real world facts”. For the social aspects, as the models are often used for consensus building, they rely on another epistemological reference: “a statement is true for a group, if and only if it is acceptable for a group”. According to Jay Forrester, the best model is the one that is “most persuasive” (Forrester, 1999). This is something very clearly demonstrated in most of the studies that involve stakeholders. The group eventually converges to the model that most of the participants can agree with. The scientist involved will certainly bear responsibility for the model results, but unless the results are sufficiently persuasive, the group will not accept the model. There is always a risk that the model produced to serve the needs of a group may be flawed and misused. The role of the scientist in this context is to point out the deficiencies within the group and beyond.

#### 4.2.5. *Choosing scenarios and indicators*

It should be noted that ‘scenarios’ in this context are used in a much more limited sense than the scenarios that are built in much detail to describe possible futures and which stand by themselves as products of research and deliberation. These may or may not involve modelling, but if it is used it is applied to refine the scenarios that are produced (Alcamo, 2008; Mahmoud et al., 2009). In the model development context, a scenario is simply a possible set of parameters and forcing functions that may correspond to some control or management mechanism. This is then fed into the model to produce the result. The scenario itself is not a result, it is just a plausible description of a management plan, a control option. This is then tested with the model to find out how the system may react (Lautenbach et al., 2009).

Stakeholders are best placed to pose solution scenarios to a problem. Many of them have decision-making power and/or influence in the community and understand the relative feasibility and cost-effectiveness of proposed solutions. In addition, engaging local decision makers in the scenario modelling stage of the research process can lead to development of more innovative solutions (Carr and Halvorsen, 2001).

Given limited resources for modelling, is it better to focus on scenarios which we, the research team, suspect will have the greatest impact on the results, or those scenarios which are most easily and therefore likely to be implemented politically? Scenarios can be very different for each perspective. By testing politically feasible scenarios, we understand the boundaries of what might reasonably be achieved in the short-term given current funding and political realities. Meanwhile, the most environmentally effective scenarios push stakeholders to think beyond conventional solutions and to recognise the boundaries and time lags involved with what they aimed to accomplish.

To help this kind of decision it is very important to identify collectively the indicators or outcomes of scenarios. These indicators, often environmental and socio-economic, will be the tools to compare the impacts of the alternative scenarios. The collective discussion on the indicators is crucial for the dialogue between stakeholders because it reveals their objectives (Etienne et al., 2003).

#### 4.2.6. *Interpreting and presenting results*

One of the main goals of a PM exercise is to come to a better decision, policy or management plan. Whereas stakeholders may have proposed scenarios based on their perception of the problem, they may be particularly adept at proposing new policy alternatives following initial model results from a scenario modelling exercise (Carr and Halvorsen, 2001). The PM process can further facilitate development of new policies through development of a collaborative network of stakeholders throughout the research process (Beirele and Cayford, 2002). Stakeholders are important communication agents to deliver the findings and the decision alternatives to the decision makers in the federal, state or local governments. They are often more likely to be listened to than the scientists who may be perceived as foreign to the problem or the locality.

An important final step in the PM process is dissemination of results and conclusions to the wider community. Presentations to larger stakeholder groups, decision makers, and the press should be made by a member of the stakeholder working group. This solidifies the acceptance of the model results and cooperation between stakeholders that were established during the participatory modelling exercise. In addition, members of the community are often more respected and have a better handle on the impact of policy decisions on local community's issues.

#### 4.2.7. *Assessment, context and generality*

It is important to learn whether the process produced the result that was required (Ahrweiler and Gilbert, 2005), and whether the results can be generalised to the extent that they may be applied elsewhere. The answer largely depends upon the objective of the participatory effort. If stakeholder participation was for extractive purposes only, to find more information about the system, then the overall assessment of the process will be similar to what one would do for a regular modelling effort. We would estimate whether the right data and knowledge were collected and evaluate how well the model fits the reality. Traditional methods to compare the behaviour of the model and the real system can be used, and results can be found that are general enough to apply in similar context for analogous systems.

If the process was to enhance awareness, to facilitate a learning process, to promote the emergence of a shared representation, co-learn and co-construct, then we need to evaluate the learning process and assess the role that modelling played in this learning process. Surveys, questionnaires and protocols are the most appropriate evaluation tools in this case.

There is always a trade-off between the context and the generality. A lesson drawn from a model should ideally go beyond a given local context. However in the case of co-constructing, the structure, the content and the results of the model often stay very close to the application at stake and it is sometimes difficult to estimate the meaning of the model and the simulations for other locations, or to base theoretical conclusions on them.

As Creighton (2005) puts it, “Public participation remains a craft, not a science. I don’t think it will ever be different. It partakes too much of the messy emotional stuff of intense human interaction, struggles for power, and strongly-held beliefs about what’s good for our societies.” This certainly applies to modelling with stakeholders. It is important to actively involve social scientists in the PM process perfecting our skills of formalising the beliefs, the powers and values that drive the behaviour of humans and their interactions. However, it may take some time for the theory to grow to fruition. Until then generalisations will be hard and we will still find most of the applications rather localised and unique in terms of the experience that they produce.

## 5. Conclusions. From participatory modelling to collaborative decision making and adaptive modelling

Conclusions can be drawn in three directions: social, instrumental, and methodological.

### 5.1. Social aspects

The drive toward participatory decision making is primarily fuelled by the increasing realisation that the more humans impact the environment and the more they attempt to manage natural resources, the more complex and less predictable the overall socio-ecological system becomes and the harder it becomes to find the right decision and to choose the best management practice. PM helps to ‘level the playing field’ (Campo et al., 2010) for decision making by providing a common pool of knowledge and data that is delivered in the process of shared learning by the stakeholders. PM can also improve communication between formerly disconnected groups of stakeholders (Gaddis et al., 2010), providing a common language for interaction and dispute resolution (Metcalf et al., 2010), which leads to more consensus and easier and better decisions.

However some sensitive issues exist in the social domain. One important question is whether the PM process is mutually beneficial of there can be losers and winners. Who is empowered and who is disempowered? (Abbot et al., 1998; Chambers, 2006). These questions are relevant to any process where different organisational or hierarchical levels are involved (Castella et al., 2005; Kok et al., 2007). It is important to combine the iterative learning dimension of adaptive management and the networking dimension of collaborative management, in which rights and responsibilities are shared. The concept of adaptive co-management was proposed (Olsson et al., 2004), suggesting that all stakeholders should participate but in certain cases there must be an option to work separately, at least for some time, giving the stakeholders a chance to deal with the power issues. Although each application is context specific, we think that the participatory modelling efforts provide material for general insights on political issues on natural resource management.

The role of scientist is also important in the social process. Above we mentioned the role of a scientist as provider of scientific knowledge. But equally important in the social process is the role of a scientist as a neutral, mediating person.

There are always concerns about the future of participatory efforts. What happens when the researchers are done with the project and move on to other studies? Unfortunately in far too many cases the projects die with the end of the funding and once the scientific team leaves. Continuity and lasting support is usually not written into project proposals and funding agencies do not have provisions for that kind of support. At the same time during the project the modelling skills of stakeholders are rarely brought to the level when they can run and further develop the models themselves. This is clearly an area where improvement is needed. The development of long-term partnerships between modellers and model end-users is fundamental to promoting on-going adaptive management (Walters, 1986; Jakeman et al., 2009).

If trust is built between the two groups and the broad problem issues being addressed are ones of continuing concern (e.g. ecosystem health), then it is likely that funding sources for the collaborative efforts in improving management outcomes can be identified. Even as sources and topics for funding change, ways can often be found to reorient the work to capture such funding. Pursuing robustness in the relationships should be a major aim, making sure that it is not dependent on one individual champion.

### 5.2. Instruments, tools and techniques

The PM process is about problem solving, less about modelling. For example, looking at papers in this Thematic Issue, it may seem that there are hardly any breakthroughs in modelling techniques that have come from a stakeholder process. We may be getting better decisions and policies, but what are the benefits for the modelling trade? If we look at how collaborative model projects are developed, there is a clear similarity with the open source paradigm in code development, when software is a product of joint efforts of a distributed group of players (Voinov et al., 2008a,b). Ideally the participatory process should ‘live’ on the web and continue beyond a particular project. It is a valuable asset for future decision making and conflict resolution. It can stay alive with incremental funding or even donations, with stakeholders able to chip in their expertise and knowledge to keep it going between peaks of activity when bigger projects surface (Voinov and Costanza, 1999). This could be a way to maintain the ‘memory’ of the project, which is essential for future learning and reuse of results, especially when re-scaling to larger institutional or regional units. Unfortunately the web and modelling tools that would provide this kind of functionality and interoperability are still quite rudimentary, although there have recently been some promising efforts in this direction (e.g. Eckman et al., 2010).

Regardless of whether or not the model lives on beyond a project, it is important to value the process of developing a model in collaboration with a stakeholder group as much as the model results themselves. The modelling process offers many benefits beyond deriving results including identifying data gaps, gaining an improved understanding of the system, and incorporating multiple perspectives into the understanding of a system.

While adaptive management has become a buzz word for more than a decade, there is little understanding so far that adaptive management is impossible without adaptive decision making and **adaptive modelling** (Norton and Reckhow, 2006; Lynam et al., 2010). Adaptive modelling has become a topic in engineering and computer sciences (AML, 2009), but there are only a few mentions of this in the environmental literature. SCOPUS returns only one reference (Seneviratne and Karney, 1993), in addition to a mention



of adaptive modelling in [Leavesley et al. \(2006\)](#). Adaptive modelling should clearly become a standard in the decision-making process under uncertainty, and stakeholder involvement is crucial to make it happen.

### 5.3. Methodology

It has been long understood that the modelling process should be iterative, that it is hardly possible to make a good model from start, that models should serve the goal and should always be improved during the modelling process ([Jakeman et al., 2006](#)). The on-going involvement of stakeholders becomes important in tracking the goals and providing guidance throughout the process. Stakeholder participation certainly helps to relate the models with the real needs, and can feed and invigorate the modelling process with new data, ideas and needs.

Stakeholder participation makes the modelling process truly adaptive, so that models can adequately incorporate new information about the systems as it becomes available and adjust to the new goals driven by the decision making and management needs. It has been a while since [Korfmacher \(2001\)](#) proposed guidelines for good practice in participatory modelling, which call for a transparent modelling process, continuous, appropriately representative involvement, influence of participants on modelling decisions and a clear role of modelling in management. These guidelines are still relevant as shown by [Johnson \(2007\)](#) and the several case studies presented in this issue. The challenges seem to shift into the relational, social dimension of the process, that can help us identify differences and similarities in various case studies to identify patterns and ways to learn from the experience of the others.

How can we make the PM process better accepted and used, how do we involve the right people and parties, what are the connections between the stakeholders, between stakeholders and organisations in different hierarchical levels defined by their access to power and governance, who is controlling the process, what is the past history and evolving progress of interactions between the participants ([Becu et al., 2008](#)), what type of information is exchanged and produced during the process? Although we are not at the stage of proposing general conclusions, this thematic issue presents a series of case studies which further our understanding of the PM process.

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