CHAPTER THREE

Bridging the Gaps Between Design and Use: Developing Tools to Support Environmental Management and Policy

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3.1. A Gap Between Design and Use?

Sound decisions in environmental policy and management usually require the examination of alternative solutions, and may require the consideration of alternative problem formulations prior to option assessment. Constructing and considering the consequences of alternative problems (variables and relations) and policy options (norms and standards) is fundamental for processes of policy formulation (Vickers, 1965).

Formal computer-based decision and information support tools (DISTs) can provide a means of structuring and exploring problems, and of generating qualitative and quantitative information for analysing and characterising decision spaces. In particular, tools such as integrated assessment models (IAM) (e.g. Parker et al., 2002), decision support systems (DSS) (e.g. Giupponi, 2007) and GIS (e.g. Van Lynden and Mantel, 2001; Malczewski, 2006) have been identified as suited to providing support to complex decision processes through fulfilling a number of roles (Van Daalen et al., 2002). However there are recognised gaps between the claims made about the usefulness of such tools and their demonstrated utility in environmental policy and management (Reeve and Petch, 1999; McCown, 2002; McIntosh et al., 2005). The key question of this chapter is why, and what, if anything, can be done in terms of improving tool design for greater usefulness and usability?

With this chapter we shall progress towards answering these questions as a means of informing and improving tool development practice. We shall first of all present a brief review of DIST technology as used for environmental policy and management, then identify different categories of users and use for DISTs. Supporting organisational decision making and participatory (or collaborative) decision making will be discussed in detail. We will then turn our attention to better understanding the nature and extent of the gap between design and use before presenting and discussing a set of good practice guidelines for user involvement in tool design as means of bridging the gap.

3.2. Decision and Information Support Tool Review

Decision and information support tools (DISTs) represent a broad and diverse category of computer-science based instruments. In this section we will present a mini-review of recent examples of DISTs applied to environmental policy and management.

We will start with decision support systems (DSS). DSSs can support the organisation and analysis of information in such a way that policy makers are able to compare different strategies, and to integrate their own priorities and value judgments in the decision making process transparently (Mysiak et al., 2005). The computational ability of DSS to solve well-posed problems (e.g. identify optimal multivariate tradeoffs) is undoubted, but their ability to support problem formulation has received some critique (Courtney, 2003).

Environmental and natural resource management problems are often complex, uncertain and value-laden and as a consequence systems approaches which integrate issues, stakes, disciplines and scales are indispensable. To fulfil these needs the approach of Integrated Assessment (IA) (Gough et al., 1998) has emerged to integrate 'knowledge from different disciplines with the goal to contribute to understanding and solving complex societal problems that arise from the interaction between humans and the environment'. Within this approach Integrated Assessment Modelling (IAM) (Parker et al., 2002) has been developed to integrate analysis of socio-ecosystems.

Two main categories of modelling approaches used in DISTs can be distinguished within IAM – predictive and goal-oriented modelling. Predictive models are suitable for developing a mechanistic understanding of biophysical processes in environmental systems, and their human and non-human drivers (Parker et al., 2002). Goal-oriented approaches can be divided into two types: (i) optimisations which aim to find an optimal allocation of resources to satisfy a given (set of) objective(s) under certain constraints (e.g. Marshall and Homans, 2006; Crossman and Bryan, 2006; Strange et al., 2006); and (ii) exploratory models which generate multiple futures to explore the consequences of a range of resource-use combinations and management practices (e.g. Matthews et al., 2005).

Social dynamics are increasingly incorporated directly into DISTs. Agent-based modelling (ABM) is an approach primarily used to simulate the dynamics and behaviour of individuals or groups of animals or humans. An agent represents an object in an environment that senses and communicates with other agents and the environment. On the basis of a predefined set of rules it reacts to changes, has its own goals and uses the environment to achieve these goals (Topping et al., 2003), thus providing a potential link between biophysical and social processes (e.g. Berger, 2001; Parker et al., 2003). Whether ABMs and other computer models of social process can adequately represent and be used to explore the behaviours of humans is a point of debate.

Beyond using computer models to explore human behaviour, DISTs are being used to directly influence action in the world through challenging and changing beliefs. The concept of using models and other DISTs as devices to provoke and promote dialogue, debate and deliberation between stakeholders has emerged as a way of directly influencing behaviour instead of forecasting (Guimãres Pereira et al., 2003). This mode of use is directly linked to the participatory governance agenda and will be discussed in detail later.

The scope of DIST use is clearly broad and of potential relevance to a wide range of users. Potential users of DISTs can be categorised into governmental (e.g. local, regional or national), private enterprise (e.g. manufacturing, service or utility companies), Non-Governmental Organisations or NGOs (e.g. conservation charities) and research (e.g. Universities or Government research agencies).

In addition to these users, three broad categories of use for DISTs can be distinguished including scientific research, organisational decision making and participatory and collaborative decision making. It should be noted that by scientific research we mean research concerned with the generation of generalised, objective knowledge, whereas policy or management research (as we view it) is concerned with the generation of context specific, action-oriented knowledge. The differences we allude to are similar to the differences between Mode I (traditional) and Mode II (policy relevant) research (Gibbons et al., 1994), and also the difference between normal and post-normal science (Funtowicz and Ravetz, 1993).

Different types of DIST suit each use, and each use presents particular challenges to tool developers (see for example the contrast between research and policy uses for models presented by Oxley et al., 2004). We will explore these challenges in the following sections, focusing particularly on characterising challenges associated with developing tools to support Governmental, Private Enterprise and NGO users with regards organisational and participatory decision making. We will not discuss DISTs for scientific research.

3.3. Supporting Organisational Decision Making

Supporting organisational decision making involves designing tools to provide relevant information in a manner which suits, and ideally improves the way in which the employees of that organisation work together to achieve collective action (Checkland and Holwell, 1999). Two main uses for DISTs can be distinguished with respect to support of organisational decision making:

(1) The support of decision making aims within an organisation. In this case the DIST provides information which can directly guide decision solutions. There will be different demands placed on the DIST depending on whether strategic, management or operational processes are to be supported (McIntosh et al., 2005).

(2) The DIST that provides a decision platform for agreements in external policy negotiated between organisations. In this case the impact of DIST analyses may be less direct or identifiable (Ho and Sculli, 1995), although DIST can be used in structured processes to facilitate negotiation between different parties (Castelletti and Soncini-Sessa, 2006). There are similarities here with participatory decision making which will be covered in the next section.

One of our concerns is that DISTs are often not designed to support what people in (environmental management and policy) organisations actually do within their current practice (i.e. the purpose and structure of organisational action in terms of tasks or activities – see Checkland and Holwell, 1999). Rather, DISTs embody an implicit argument for change in action as perceived by the (often academic) DIST development team, because the functionality built into a DIST requires certain behaviours from users (Akrich, 1992). It should therefore not be surprising that in such cases the tools available are not used – they cannot be (or at least not without the necessary organisational change).

To help avoid agenda conflicts or confusion between two different objectives (supporting and changing organisational action) we think environmental DIST developers would benefit from clearly stating their objectives for each tool as:

(1) to be used by the people designing the tool as a research or consultancy service; or

(2) to be used by people in an external, specified end-user organisation to support:
- **(a)** existing forms of organisational action through providing currently used information in a more efficient way; or
- **(b)** existing forms of action through providing new information in such a way that it is hoped the effectiveness of organisational action will be improved; or
- **(c)** an alternative form of organisational action through providing new information in new ways; or

(3) not to be used routinely at all but to demonstrate some methodological or technological advance, which may be of future benefit.

The design objectives of a tool partly determine the way in which the tool should be developed. Design objectives (1) and (3) above require little consideration of how people other than the tool designers work. Under such circumstances there are no strong pressures to use one design or development method over another, except that it must suit the design team. This is not the case with design objective (2). Here it is crucial to understand the system that is to be supported (people collectively acting in an organisational setting with particular performance measures) before the system that supports (the DIST) can be designed (Checkland and Holwell, 1999). Specific organisational structures like hierarchies and the degree of cross-organisational use of DIST (e.g. across departments) can place different requirements on design that need to be taken into account (Vetschera, 1997). Design under these circumstances must be demand-pull in orientation (Reeve and Petch, 1999) and may have to use 'socio-technical' methods during the development process to characterise and better reflect organisational information and information processing needs in tool design. Therefore, at least the interface with the end-users, if not the entire model development itself, should try to conform to the preferred communication systems of targeted end-users.

3.4. Supporting Participatory and Collaborative Decision Making

Participatory modelling draws on the theory of post-normal science, which suggests that in problems characteristic of highly complex systems, when facts are uncertain, values in dispute, stakes high and decisions urgent, there is no one correct, value neutral solution (Funtowicz and Ravetz, 1993). When we cannot say exactly what the outcome of the decision will be, it makes perfect sense to involve those people impacted by the decision in the decision-making process. This is a way of improving the decisions by tapping into the specific local knowledge, and sharing the responsibility for decision making.

It should be noted that participatory modelling (with different clones also known as 'mediated modelling' or 'shared vision modelling') is not about the model, but about the decision making. Using the knowledge, concerns and demands of the stakeholders (people who influence a decision, or can influence it, as well as those affected by it – Hemmati, 2002) in the participatory tool development process may result in better tools to support decision making and a broader and more balanced view of the issues involved (Jakeman et al., 2006). The modelling process itself becomes the decision-making tool. At the same time the process of participatory model development enables stakeholders to learn about variables and interactions of "their own" systems and "their own" decisions (Pahl-Wostl, 2006).

Ideally the participatory modelling process should start with a blank page, when scientists interact with stakeholders to define the goals of the model and then choose the most appropriate existing models or modules for their further improvement and application. Stakeholder participants can engage in the decision-making process in the form of model selection and development, data collection and integration, scenario development, interpretation of results, and development of policy alternatives.

Besides the basic knowledge exchange for the model construction a learning process is initiated by collaborative working which leads to the construction of shared problem perceptions and the communication of different views. This can be facilitated and supported for example by applying system science (Pidd, 2003) to describe and better understand:

- the key players and processes in the system;
- the interdependencies and interactions of different components within the system;
- external factors and driving forces influencing the system and thus;
- the system behaviour as a whole.

It should be noted that organising and maintaining a participatory process is resource intensive with regards time and money. This has to be taken into account seriously while designing the participatory approach. Potential stakeholders (as well as the scientist organising the participatory process) are often restricted by time constraints and/or insufficient funding. Careful attention has to be paid to planning common actions wisely (e.g. workshops, round-table meetings, and role game sessions) and to ensuring that the costs of stakeholders to participate in these actions are covered. Such preparatory work increases the willingness (besides other factors) of the stakeholders to attend the process and lowers the danger of stakeholder burn out (e.g. as a result of too many meetings). Moreover, the form of participation (active in model or tool discussion/development or passive "listening") is decisive for the outcomes and impact of the stakeholder process.

3.5. The Nature and Extent of the Gap

So there is little doubt that computer-based DISTs have the potential to play critical roles in supporting environmental management and policy decisions, either in organisational or participatory contexts. The ability to realise this potential is dependent on whether we, as a community of technologists (largely but not exclusively), successfully confront the perceived and actual gap between design and use. Two broad questions we must address:

- What is the extent and character of the gap?
- To what degree, and how, can the gap be bridged?

If either a developer or an end-user was asked whether there was a gap between design and policy integration of a modelling tool, it is likely that the answer would be affirmative, however qualified. Unfortunately however there is little quantitative evidence to characterise the nature or extent of any gap.

Reeve and Petch (1999) provide a short, focused review of evidence on the benefits of GIS technology to users such as UK local government authorities. They also review other studies into GIS business benefits (e.g. Campbell and Masser, 1995) and find a broadly uncertain picture with high costs and difficult-to-determine benefits.

Jeffrey and Seaton (1995) report survey results from operations research (OR) practitioners from different application sectors on the use of various OR techniques like simulation and optimisation. The survey reveals a complex picture. Different OR techniques were used or not used in different sectors for different reasons. Noted among the advantages of using OR techniques were a broader understanding of complex problems, and a structured approach to problem solving. Disadvantages listed included erroneous interpretation of results, and a lack of attention to soft or behavioural issues.

Sojda (2007) argues that empirical evaluation of a DSS is an essential element of development and distinguishes two elements – internal consistency (verification) and usefulness to the intended user (validation). The question of evaluating usefulness is addressed from the perspective of determining whether the DSS fulfilled its design purpose. This is a pity as it avoids asking the more difficult and crucial question of 'does the design and implementation of the DSS provide benefits to the intended user?'

There are of course success as well as problem stories. With regards to GIS for example, Balram and Dragicevic (2005) show, in a study of urban green spaces in Montreal, Canada, that integrating questionnaire surveys and collaborative GIS techniques improved attitude measurements. Castelletti and Soncini-Sessa (2006) report the use of a multiobjective DSS within a participatory planning process to successfully identify and select a set of planning options for the Lake Maggiore water system. However they also note that implementation of the selected option set has been delayed by a call for further studies by one Governmental stakeholder. Gaddis et al. (2007) describe a successful participatory modelling exercise at the scale of local government. While the study has led to consensus between various stakeholders, again it is not clear to what extent the results actually got translated into decisions made. Within the US Army Corps of Engineers there is a strong push towards collaborative decision making, called Shared Vision Planning (SVP) advocated by the Institute for Water Resources. The SVP approach has its origins some 30 years ago and was presented in numerous Corps reports (Wagner and Ortolando, 1976; IJC, 2006), but was never adequately described in scientific literature. While the Corps seems to embrace the approach as a solution to lengthy litigation that often follows their planning and regulatory decisions, there is a gap even within the Corps between the SVP advocates that require open transparent modelling tools and their modelling division, HEC (http://www.hec.usace.army.mil), that is entrenched in the suite of models that they have developed over the years, and are reluctant to take the open source – open model path, even though the models themselves are free to download.

To better characterise and understand the gap we need to develop a more sophisticated view of what constitutes successful decision or information support. Success is currently informally measured predominantly by whether the tool was used as the developer intended. In these terms, failure then is claimed when the system or model is not applied to solve the intended policy problem or when model results are not directly translated into policy. This limited viewpoint is, perhaps, responsible for much of the perception of a gap between design and use. It must be recognised that essential learning processes can take place even when model development is halted, the system was not used operationally or an alternative solution is implemented because the original problem framing has been abandoned as weak in some regards. Bell et al. (2001) describe a case where decision makers were able to get detailed insight into the decision problem by using the DSS, yet the adopted solution differed from the one proposed by the DSS.

Indeed, it is clear that there are problems in both recognising and in measuring the impacts of the use of DISTs against a background of competing influences. Sterk et al. (2006) studied the use and impact of whole-farm models in developing sustainable farming systems. They concluded the impact was on the process of 'reframing,' defined as the recognition of problems, interests and mental models of parties involved rather than on any environmental indicators per se. Castelletti and Soncini-Sessa (2006) come to a related conclusion in stating that the aim of the decision-making process is to increase the understanding of all of the actors involved with the problem, to allow them to formulate requests that are increasingly precise and to form opinions that are better-informed by technical analyses and by highlighting the social learning function of their DSS.

To continue to refine our understanding of the gap between design and use it will be necessary to first formulate a less restrictive definition of DIST success – a definition not solely focused on the implementation and use of a piece of software, but one that includes wider benefits such as collective learning, encouraging partnership, and improved problem specification (see work by Putnam and Holmer, 1992; Sterk et al., 2006; Van Ittersum et al., 2004; Walker, 2002). Next, there is a great need for systemic research to gather and disseminate comprehensive data on the "gap between design and use."

However, as a community of researchers and tool developers we have accumulated a significant knowledge base of how, and how not, to go about the process of developing DISTs. Until we better understand the nature and extent of the gap empirically it is accumulated practitioner know-how that offers an opportunity for improving tool design.

3.6. Good Practice Guidelines for Involving Users in Development

With any proposal for the use of DISTs in environmental policy and management careful consideration needs to be given to how best to involve users and other stakeholders in the development process. In particular useful lessons may be derived from the experience of developers in other sectors (McCown, 2002). Good development practice clearly exists within the environmental modelling and software community but is fragmented. The aim of this section is to bring together lessons learned, and to identify remaining issues with regards supporting organisational and participatory decision making.

3.6.1 Know the capabilities and limitations of DIST technologies

Improvements in graphical user interfaces and visualisation have made computer-aided support accessible to a wider audience. The new accessibility of these tools has come with an inherent risk that they will be misapplied or misinterpreted and the results oversold. Inherent difficulties in understanding and communicating the uncertainties of the underlying bounding decisions and data upon which DISTs depend can compound the dangers of overselling.

While the tools can appear more accessible, developers must be careful in managing stakeholder expectations so as to avoid disappointment and eventual abandonment of DIST technologies (Haase and Lenssen, 2005; Matthews et al., 2005). It is essential to recognise that many of the environmental decisions to be supported are uncertain, preference and power dependent and scientifically contested (Rauschmayer and Wittmer, 2006). Simply supplying more information will not necessarily result in improved management, or even necessarily address the 'right' set of issues. Tools must first of all be relevant to be useful (Checkland and Holwell, 1999).

3.6.2 Focus on process not product

It is also important for tool developers to understand and engage with processes of decision making. Expertise is built up collaboratively through dialogue between interested parties and may be as significant an output as the software tool itself. Collaborative learning within the decision making process is also essential to ensure that when tools are applied they adequately reflect local circumstances Such learning with users and the subsequent incorporation of user knowledge within tools is indispensable when seeking to increase the credibility of tools with stakeholders (Haase and Bohn, 2007).

However, there remain significant differences in agenda and performance criteria between primarily academic tool-developing research organisations and primarily non-academic tool-using organisations. Caminiti (2004) discusses these differences and suggests a process to control development from a user perspective. Given the potential costs involved in developing and using models and model-based tools it may also be necessary to formally monitor or at least assess post-hoc the benefits (tangible and intangible) of using model-based tools within decision making processes compared with existing processes.

Development process aside, the value of a decision or information support tool is realised through use, as a means of supporting decision-making processes. Examples of the deliberative use of DISTs to support particular processes include exploring options related to water quality in California, USA (Quinn et al., 2005) and zoning coastal waters for a series Marine Protected Areas in southern Australia (Crossman et al., 2007). Both Hare et al. (2003) and Guimãres Pereira et al. (2003) provide reviews of the literature in this area.

3.6.3 Understand roles, responsibilities and requirements

Developers need to be clear about who are the end-users (who will employ the tool), clients (who fund the development) and stakeholders (who have an interest in the tool's outputs or process of using the tool), and what are the circumstances under which the tool will be used. Many of the failures of computer-based decision support can be attributed to developers failing to understand the relative roles, responsibilities and requirements of the different parties involved. Fundamental misunderstandings and disagreements are possible on: (i) the expectations and responsibilities of the participants in the process; (ii) what constitutes a legitimate form of knowledge; and (iii) how different forms of knowledge can be elicited and accommodated within tools or processes (Haase and Lenssen, 2005).

The nature of the role that tools are intended to occupy may also be significant. Where new tools seek to improve on existing systems (such as paper records or simple spreadsheets) then there is a greater likelihood for their adoption and use as they fit with existing patterns of work. The other successful role identified for software tools is as aids to consultancy, where the credibility of the tool depends less on the technical or presentational aspects of the software and more on the skills of the operator in running and interpreting the outputs (Carberry et al., 2002).

3.6.4 Work collaboratively

A wide variety of methods to support collaborative working between developers or between developers and end-users/stakeholders are available. Many such methods have their origins in fields of study such as community-based conservation (Berkes, 2004) or participatory democracy (Dryzek, 2000) but others are associated with systems research such as Soft Systems Methodology (Checkland and Scholes, 1990).

Including social scientists in development teams may help through providing a theoretical background to frame the design of the process, to evaluate whether the methods proposed can achieve the design goals and to interpret the outcomes. Development teams need to move beyond interdisciplinarity (the focus on combining approaches from different disciplines) to integrate disciplinary, academic and practitioner knowledge in trans-disciplinary working (Aram, 2004). However such work is not cheap – do the additional overheads involved outweigh the potential benefits of the DIST being developed?

3.6.5 Build and maintain trust and credibility

For any decision-making process there will be actors who need to be convinced of the benefits of using the tools. The lack of credibility with such actors for many computer-based tools stems from the lack of time devoted by research teams to social networking compared with the effort spent on the technical aspects of development. An important component of the successful collaboration described in Monticino et al. (2006) was the close connection between municipal staff and university researchers (many city officials received their degrees from the university).

It is vital that our development practices build social and scientific credibility. To be scientifically credible DISTs should be transparent, validated and peer reviewed (Hilty et al., 2006; Rykiel, 1996) – whereas participants may determine the questions that the model should answer and may supply key model paradigms and parameters, the structure of the model must be scientifically sound. To be socially credible DIST developers must establish trust with end-users, clients and stakeholders. Both scientific and social credibility depend upon characterising and communicating uncertainty where it exists.

Social credibility depends upon openness and transparency, particularly with regards the underlying assumptions within the tools and what has been left out. 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. In this regard documentation of tools (a much neglected area) and adopting formal quality assurance protocols may be necessary especially where the underpinning science is contested (Scholten and Kassahun, 2006).

Where a tool is made available as free or open source software (FOSS) then there is potential to increase the credibility of the tool by establishing a community of users with the ability to test and further develop tools cooperatively, through online connections such as forums or through formal networks and meetings. In this regard FOSS represents a significantly different strategy for including users, stakeholders and others in the process of designing, developing and using software systems that may have potential for DIST.

3.7. Conclusions

To conclude this chapter we shall return to consider the key questions posed at the beginning – why are potential end-users often unreceptive to DIST technology, and what, if anything, can be done in terms of improving tool design?

We have reviewed in outline a broad range of DISTs and discussed the needs of different environmental policy and management uses for these technologies, specifically to support organisational and participatory decision making. The range of DISTs we have reviewed clearly have the potential to provide useful support functionality to both sets of users and uses. So, why are potential end-users unreceptive to DISTs? We have reviewed the evidence and must now qualify our position. Examples of successful (i.e. actually used to support environmental policy or management processes) and unsuccessful (i.e. not used) DIST development can both be found. But we do not have sufficient evidence to adequately describe the nature or extent of any gap between design and use.

Our reasoned conclusion is that a gap does exist but that the gap is partly a gap of perception – a gap between how we as tool developers think our tools ought to be used by others, and the ways in which they are used and do have an impact. So, in addition to turning our attention to better understanding user needs and to undertaking research to empirically establish the facts behind any gap, we need to develop more sophisticated understandings of how scientific data, information and methods, packaged and delivered in the form of DIST technology, influence and impact policy and management processes.

In the meantime we need to better integrate and exploit the growing body of experience-based know-how we are accumulating as a community to inform our design and development practices. This body of knowledge is not coherently presented within the environmental modelling and software literature and one of the key aims of this chapter was to move towards a useful synthesis and presentation.

Despite the elusive extent and varied character of the gap between design and use, a set of four key 'lessons learned' regarding successful engagement with policy and management users can be identified from the good practice guidelines for user interaction described in Section 3.6:

- *Understand user needs*. Failures of DISTs are often the results of a lack of understanding and appreciation of user of needs. Reeve and Petch (1999) stress that tool developers need to move from a 'technology push' to a 'demand pull' orientation. A proper appreciation of the socio-technical aspects of tool design and a better understanding of how to contribute to improving organisational performance are essential for successful tool development and acceptance. This accords with what is known from studies looking at response to innovation (Seaton and Cordey-Hayes, 1993).
- *Be clear about the purpose of the tool*. As a corollary to understanding user needs, developers need to be clear about why they are creating a DIST in the first place. If the aim is not to support the activities of other people then the need for the DIST is very questionable. But beyond this, tool developers need to establish whether the tool will require users to change their existing practices

(task structure, the way that work is performed). The costs involved in changing working practices can be significant and close collaboration is required to ensure the tool is developed to fit desired new working practices in such a way as to yield benefit to the user(s).

- *Work collaboratively*. One of the greatest, and frequently overlooked, benefits of projects is the insight gained by model developers, practitioners and stakeholders through a participatory development process. Such processes can make clear the contradictory objectives, expectations and perceptions between science and practice and play a fundamental role in mediating compromises from both sides.
- *Establish and maintain credibility and trust*. Model results are used to inform policy or management processes when users and other relevant stakeholders trust the practitioners developing and/or running the models. Practitioners run the models when they trust the model developers. The key to developing this trust is openness and transparency about underlying model assumptions and limitations. Another factor is developing and maintaining professional relationships with practitioners.

It is our hope that, in bringing together insights from environmental modelling and software development practitioners from across the globe, this chapter will provide a useful guide to improving environmental DIST development practice. In this regard, the chapter should be viewed as a starting point rather than a destination.

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REFERENCES

Akrich, M., 1992. The description of technical objects. In: Bijker, W.B., Law, J. (Eds.), Shaping Technology/Building Society: Studies in Sociotechnical Change. MIT Press, Cambridge, MA.

Aram, J.D., 2004. Concepts of interdisciplinarity: Configurations of knowledge and action. Human Relations 57, 379–412.

Balram, S., Dragicevic, S., 2005. Attitudes toward urban green spaces: Integrating questionnaire survey and collaborative GIS techniques to improve attitude measurements. Landscape and Urban Planning 71, 47–162.

Bell, M.L., Hobbs, B.F., Elliott, E.M., Ellis, H., Robinson, Z., 2001. An evaluation of multi-criteria methods in integrated assessment of climate policy. Journal of Multi-Criteria Decision Analysis 10, 229–256.

Berger, T., 2001. Agent-based spatial models applied to agriculture: A simulation tool for technology diffusion, resource use change and policy analysis. Agric. Econ. 25, 245–260.

Berkes, F., 2004. Rethinking community-based conservation. Conservation Biology 18, 621–630.

Caminiti, J., 2004. Catchment modelling—A resource manager's perspective. Environmental Modelling and Software 19, 991–997.

Campbell, H., Masser, I., 1995. GIS and Organisations: How Effective are GIS in Practice? Taylor and Francis, London.

Carberry, P.S., Hochman, Z., Mccown, R.L., Dalgliesh, N.P., Foale, M.A., Poulton, P.L., Hargreaves, J.N.G., Hargreaves, D.M.G., Cawthray, S., Hillcoat, N., Robertson, M.J., 2002. The FARMSCAPE approach to decision support: Farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. Agricultural Systems 74, 141–177.

Castelletti, A., Soncini-Sessa, R., 2006. A procedural approach to strengthening integration and participation in water resource planning. Environmental Modelling and Software 21, 1455–1470.

Checkland, P., Scholes, P., 1990. Soft Systems Methodology in Action. John Wiley and Sons, Chichester.

Checkland, P., Holwell, S., 1999. Information, Systems and Information Systems. John Wiley and Sons, Chichester.

Courtney, J.F., 2003. Decision-making and knowledge management in inquiring organizations: Toward a new decision-making paradigm for DSS. Decision Support Systems 31, 17–38.

Crossman, N.D., Bryan, B.A., 2006. Systematic landscape restoration using integer programming. Biol. Conserv. 128, 369–383.

Crossman, N.D., Perry, L., Bryan, B.A., Ostendorf, B., 2007. CREDOS: A conservation reserve evaluation and design optimisation system. Environmental Modelling and Software 22, 446–463.

Dryzek, J., 2000. Deliberative Democracy and Beyond: Liberals, Critics, Contestations. Oxford University Press, Oxford.

Funtowicz, S., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25, 739–755.

Gaddis, E., Vladich, H., Voinov, A., 2007. Participatory modeling and the dilemma of diffuse nitrogen management in a residential watershed. Environmental Modelling and Software 22 (5), 619–629.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzmann, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. SAGE Publications Ltd.

Giupponi, C., 2007. Decision support systems for implementing the European water framework directive: The MULINO approach. Environmental Modelling and Software 22, 248–258.

Gough, C., Castells, N., Funtowicz, S., 1998. Integrated assessment: An emerging methodology for complex issues. Environtal Modeling & Assessment 3, 19–29.

Guimãres Pereira, A., Rinaudo, J.D., Jeffrey, P., Blasques, J., Corral Quintana, S., Courtois, N., Funtowicz, S.O., Petit, V., 2003. ICT tools to support public participation in water resources governance and planning: Experiences from the design and testing of a multi-media platform. Journal of Environmental Policy Assessment and Management 5, 395–420.

Haase, A., Lenssen, U., 2005. Potentials – Projects – People. Urban Knowledge for Reurbanisation of Inner-city Residential Areas. Gothenburg, Sweden.

Haase, D., Bohn, C., 2007. Flood vulnerability and preparedness: Model approach to mitigate the risk for local communities. In: Schumann, A., Pahlow, M., Bogardi, J.J., van der Zaag, P. (Eds.), Reducing the Vulnerability of Societies Against Water Related Risks at the Basin Scale. In: IAHS Red Book Series, vol. 317, pp. 1–7.

Hare, M., Letcher, R.A., Jakeman, A.J., 2003. Participatory modelling in natural resource management: A comparison of four case studies. Integrated Assessment 4, 62–72.

Hemmati, M., 2002. Multi-stakeholder Processes for Governance and Sustainability. Earthscan, London.

Hilty, L.M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M., Wäger, P.A., 2006. The relevance of information and communication technologies for environmental sustainability – A prospective simulation study. Environmental Modelling and Software 21, 1618–1629.

Ho, J.K.K., Sculli, D., 1995. System Complexity and the Design of Decision Support Systems. Department of Industrial Engineering. Systemic Practice and Action Research. Springer, Netherlands.

IJC, 2006. Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows. Final Report by the International Lake Ontario—St. Lawrence River Study Board to the International Joint Commission, March 2006, 126 pp.

Jakeman, A.J., Letcher, R.A., Norton, J.P., 2006. Ten iterative steps in development and evaluation of environmental models. Environmental Modelling and Software 21, 602–614.

Jeffrey, P., Seaton, R., 1995. The use of operational research tools: A survey of operational research practitioners in the UK. The Journal of the Operational Research Society 46, 797–808.

Malczewski, J., 2006. GIS-based multicriteria decision analysis: A survey of the literature. International Journal of Geographical Information Science 20, 703–726.

Marshall, E.P., Homans, F.R., 2006. Juggling land retirement objectives on an agricultural landscape: Coordination, conflict, or compromise? Environmental Management 38, 37–47.

Matthews, K.B., Buchan, K., Sibbald, A.R., Craw, S., 2005. Combining deliberative and computer-based methods for multi-objective land-use planning. Agricultural Systems 87, 18–37.

McCown, R.L., 2002. Locating agricultural decision support systems in the troubled past and socio-technical complexity of 'models for management'. In: Probing the Enigma of the Decision Support System for Farmers: Learning from Experience and from Theory. Special Issue. Agricultural Systems 74, 11–25.

McIntosh, B.S., Jeffrey, P., Lemon, M., Winder, N., 2005. On the design of computer-based models for integrated environmental science. Environmental Management 35, 741–752.

Monticino, M., Brooks, E., Cogdill, T., Acevedo, M., Callicott, J.B., 2006. Applying a multi-agent model to evaluate effects of development proposals and growth management policies on suburban sprawl. In: Voinov, A., Jakeman, A., Rizzoli, A. (Eds.), Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modelling and Software". International Environmental Modelling and Software Society. Burlington, USA, July 2006. ISBN 1-4243-0852-6. CD ROM. Internet: http://www.iemss.org/iemss2006/sessions/all.html.

Mysiak, J., Giupponi, C., Rosato, P., 2005. Towards the development of a decision support system for water resource management. Environmental Modelling and Software 20, 203–214.

Oxley, T., McIntosh, B.S., Winder, N., Mulligan, M., Engelen, G., 2004. Integrated modelling and decision-support tools: A Mediterranean example. Environmental Modelling and Software 19, 999–1010.

Pahl-Wostl, C., 2006. The importance of social learning in restoring the multifunctionality of rivers and floodplains. Ecology and Society 11 (1), 10.

Parker, P., Letcher, R., Jakeman, A., Beck, M.B., Harris, G., Argent, R.M., Hare, M., Pahl-Wostl, C., Voinov, A., Janssen, M., Sullivan, P., Scoccimarro, M., Friend, A., Sonnenshein, M., Barker, D., Matejicek, L., Odulaja, D., Deadman, P., Lim, K., Larocque, G., Tarikhi, P., Fletcher, C., Put, A., Maxwell, T., Charles, A., Breeze, H., Nakatani, N., Mudgal, S., Naito, W., Osidele, O., Eriksson, I., Kautsky, U., Kautsky, E., Naeslund, B., Kumblad, L., Park, R., Maltagliati, S., Girardin, P., Rizzoli, A., Mauriello, D., Hoch, R., Pelletier, D., Reilly, J., Olafsdottir, J., Bin, S., 2002. Progress in integrated assessment and modelling. Environmental Modelling and Software 17, 209–217.

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffman, M.J., Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. Annals of the Association of American Geographers 93, 314–337.

Pidd, M., 2003. Tools for Thinking, Modelling in Management Science, 2nd ed. John Wiley and Sons Ltd., Chichester.

Putnam, L.L., Holmer, M., 1992. Framing, reframing, and issue development. In: Putnam, L.L., Roloff, M.E. (Eds.), Communication and Negotiation. In: Sage Annual Reviews of Communication Research, vol. 20. SAGE Publications, Newbury Park, CA, pp. 128–155.

Quinn, N.W.T., Jacobs, K.C., Chen, C.W., Stringfellow, W.T., 2005. Elements of a decision support system for real-time management of dissolved oxygen in the San Joaquin River Deep Water Ship Channel. Environmental Modelling and Software 20, 1495–1504.

Rauschmayer, F., Wittmer, H., 2006. Evaluating deliberative and analytical methods for the resolution of environmental conflicts. Land Use Policy 23, 108–122.

Reeve, D., Petch, J., 1999. GIS, Organisations and People, A Socio-Technical Approach. Taylor and Francis Ltd, London.

Rykiel, E.J., 1996. Testing ecological models: The meaning of validation. Ecological Modelling 90, 229–244.

Scholten, H., Kassahun, A., 2006. Supporting multidisciplinary model-based water management projects: A user perspective. In: Voinov, A., Jakeman, A., Rizzoli, A. (Eds.), Proceedings of the iEMSs Third Biennial Meeting: "Summit on Environmental Modelling and Software". International Environmental Modelling and Software Society. Burlington, USA, July 2006. ISBN 1-4243-0852-6. CD ROM. Internet: http://www.iemss.org/iemss2006/sessions/all.html.

Seaton, R.A.F., Cordey-Hayes, M., 1993. The development and application of interactive models of industrial technology transfer. Technovation 13, 45–53.

Sojda, R., 2007. Empirical evaluation of decision support systems: Needs, definitions, potential methods and an example pertaining to waterfowl management. Environmental Modelling and Software 22, 269–277.

Sterk, B., van Ittersum, M.K., Leeuwis, C., Rossing, W.A.H., van Keulen, H., van de Ven, G.W.J., 2006. Finding niches for whole-farm design models—Contradictio in terminis? Agricultural Systems 87, 211–228.

Strange, N., Thorsen, B.J., Bladt, J., 2006. Optimal reserve selection in a dynamic world. Biol. Conserv. 131, 33–41.

Topping, C.J., Hansen, T.S., Jensen, T.S., Jepsen, J.U., Nikolajsen, F., Odderskaer, P., 2003. ALMaSS, an agent-based model for animals in temperate European landscapes. Ecological Modelling 167, 65–82.

Van Daalen, E., Dresen, L., Janssen, M.A., 2002. The roles of computer models in the environmental policy life-cycle. Environmental Science and Policy 5, 221–231.

Van Ittersum, M.K., Roetter, R.P., van Keulen, H., de Ridder, N., Hoanh, C.T., Laborte, A.G., Aggarwal, P.K., Ismail, A.B., Tawang, A., 2004. A systems network (SysNet) approach for interactively evaluating strategic land use options at sub-national scale in South and South-east Asia. Land Use Policy 21, 101–113.

Van Lynden, G., Mantel, S., 2001. The role of GIS and remote sensing in land degradation assessment and conservation mapping: Some user experiences and expectations. International Journal of Applied Earth Observation and Geoinformation 1, 61–68.

Vetschera, R., 1997. Decision Support Systems in Networked Organizations. University of Vienna, Management Center, Vienna, Austria.

Vickers, G., 1965. The Art of Judgment: A Study of Policy Making. Chapman and Hall, London.

Wagner, T.P., Ortolando, L., 1976. Testing an iterative, open process for water resources planning. Fort Belvoir, VA: U.S. Army Engineer Institute for Water Resources. 66 pp. (IWR contract report No. 76-2).

Walker, D.H., 2002. Decision support, learning and rural resource management. Agricultural Systems 73, 113–127.