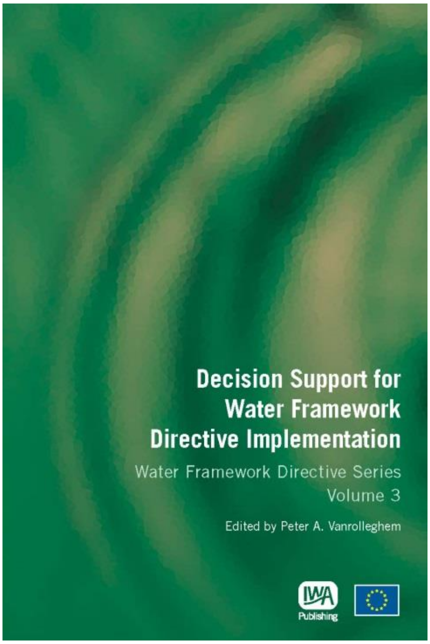
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Guidance Report III.2

Decision Support Systems for water resources management: Current state and guidelines for tool development

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Abstract
This guidance report reviews and summarises the most recent achievements and the current issues in the domain of Decision Support Systems (DSS) with specific reference to the field of water resources management. The focus is on the role of DSS tools for river basin management, having the EU Water Framework Directive (WFD) as the most important policy reference. The report investigates the reasons for the limited operational implementations of the DSS tools in the domain of interest, in order to learn from previous experiences and thus be able to propose a list of best practices in form of Guidelines for future developments and applications.

The targeted audience is broad and includes policy makers and scientists. To approach such a great variety of readers, the format of this report is subdivided in sections, with an executive summary presenting the contents of each section, allowing the reader to select the parts of interest. Table 2.1 provides a key for the different categories of readers, identified with the four categories of actors usually targeted by the activities of the Harmoni-CA concerted action.

This guidance report may be useful for various reasons. First of all it may be useful to assess the actual return of research efforts in the development of DSS tools, since the scientific projects designed to develop DSS are not normally required to monitor the implementation and application of the DSS beyond the end of the research grant. Another reason is to trigger a wider discussion about best practices in scientific policy support in general. Section 7 provides specific guidelines for future developments of DSS tools that could be of interest for all the four main categories of actors (in particular for the technology providers) and also for the funding agency (e.g. the E.C.) that may find useful suggestion for targeting future investigations.

The contributions of end users to the survey, and their involvement in writing and revising the document represents the main novelty of this report, as compared to several

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Table 2.1 Readers' guide to guidance report III.2

Part of the guidance document	Main beneficiaries: Methodology providers	Technology providers	Operational managers	Policy makers
(1) Executive summary	**	**	**	***
(2) Introduction	***	***	***	***
(3) Methodological background and literature review	***	***	*	*
(4) The perspectives of DSS' end-users	*	*	***	*
(5) Review of potential end users needs that could be met by DSS tools	**	**	***	**
(6) Drivers of the implementation success or failure	***	*	*	*
(7) Guidelines for the development, implementation and application of DSS tools	**	***	**	**

other reviews and assessment efforts on the same topic recently released by research projects or published in the scientific literature.

The evidences collected during the survey and literature review were merged with the experiences of the authors in various projects, including Mulino, DSS-Guide, Transcat, Harmoni-CA, Newater, Nostrum-DSS, and Brahmatwinn.

Keywords
Decision Support Systems, Mathematical Modelling, Water Quality Management

1. EXECUTIVE SUMMARY

1.1. Water Management DSS

There are many different understandings of what Decision Support Systems are, what they are composed by, what they do (or should do) and how. They include a vast variety of methods and tools developed for diversified purposes and contexts and for that reason providing a unique definition is practically impossible. A computer-based tool is surely one important component, but more and more DSS is intended as a broader combination of the tool(s) and the process of structuring problems and aiding decisions (Section 2 provides an introduction to DSS concepts and terminology).

DSS in the water management sector usually consist of simulation models, and/or of techniques and methods for decision analysis, recently extended to include the support to participatory processes. Therefore, a DSS typically integrates multi-source geographically referenced data and data management systems, a variety of models and elaboration procedures within a customized user interface. Emphasis is given to hydrologic models accompanied by environmental assessment and/or socio-economic evaluation. The models include both those aimed at reconstructing and simulating the physical reality, and those constructed to manage divergent objectives and to find a compromise among the expectations of different actors in a participatory process.

In an idealized view DSS should act as mediators between science and policy/decision making and as catalysts of trans-disciplinary research.

Methodological proposals and tools have been developed since the 1970's. Unfortunately, DSS have found very limited implementations in the real world, thus demonstrating that most of the DSS tools developed so far have failed to meet the objective of being used in the real world (in Section 3 a brief methodological overview and a literature review are provided).

The question arises then, whether realism could allow us to make proper and effective use of – improved – DSS, or whether abandonment should be preferred. We will not provide a definitive answer, but we will identify a set of best practices to be implemented with realism, to provide the ground for more effective future developments and applications (see Box A below and Section 7 for details).

1.2. Models, DSS tools and Integrated Water Resources Management (IWRM)

As the conflicts for water have exacerbated and the policies have become more articulated and complex, more scientifically robust methods are needed by managers and policy makers. The challenges imposed by the implementation process of the Water Framework Directive (WFD) and the putting in practice of the principles of Integrated Water Resources Management (IWRM) are emblematic in this regard. Those challenges may represent an important triggering factor for the development of improved DSS tools and, indeed, the 5th and 6th Framework Programmes of European research mobilized significant financial resources, targeting that process.

Unfortunately, in the attempt to cope with issues of increasing complexity, methods and computer tools (simulation models in particular) have shown a tendency to become more and more sophisticated and complicated, and there is a growing gap between the specialized knowledge of the DSS developers and the application of this knowledge in decision making.

1.3. The perspectives of DSS end users

In order to investigate the reasons for the frequent failures of DSS tools in being adopted by the intended end users (i.e. water managers and policy makers), the report includes substantial contributions from outside the academia and from representatives of the community of DSS end users who were involved in the writing and compiling of an ad hoc questionnaire.

The scope of the questionnaire was to acquire insights into actual and potential users' needs, expectations and satisfaction, during the tools' development and application.

As a prerequisite for consideration in this report the responses to the questionnaire given by DSS users had to be distinct from those given by DSS developers. This dramatically limited the choice of tools, since it became clear very soon that DSS applications are seldom used outside/after the original development process and/or by users different from the software developers. The objective of examining the ten tools and collecting at least two end-users' questionnaires for each tool was very challenging and was met only after great efforts and after several selected DSS were discarded (details about the results are provided in Section 4).

Neither the selection of DSS nor the information collected through the questionnaires are intended as representative samples of the universe of tools and application cases, but at least this work is probably the first attempt to involve potential end users in assessing the outcomes and the impacts of recent research efforts in developing water management DSS.

Most of the respondents reached were specialized in the field of water planning and management; just a few were experts in modelling. In general they were advisors or policy makers, although a significant portion consisted of researchers involved in DSS' applications in the context of case studies.

Most of the users reached were at their first experience with a DSS. The main motivations for that new experience were acknowledged to be a proposed partnership from research institutions and the emerging needs or inability of the previous management system to approach increasingly complex decisions. Most frequently, the main aim for developing and acquiring the DSS was to encourage and simplify stakeholders' involvement. Other frequent motivations mentioned by the end users were the need for an enhanced identification of alternative policy options and for providing transparency to previous policy decisions. The satisfaction of specific regulatory obligations and requirements, i.e. the implementation of the WFD, was also pointed out as a target of the tool application. Section 5 goes deeper in the systematic analysis of the needs and the potential role of science.

In the users' opinion, the adopted DSS is useful in a broader context, not just informing the choice of policy, but facilitating the planning process and learning among the actors, contributing to finding a compromise among different expectations and interests.

The adoption of DSS to simplify stakeholders' involvement did not necessarily make the decision making process easier. In some cases this was due to the inadequate technical features of the systems. In other cases the use of the DSS evidenced the poor quality of the input data, or failed to provide an effective user interface or to communicate hidden uncertainties. Moreover, the lack of cooperation between the partners beyond the development project was pointed out as one reason for limited use and, in some cases, even the failure of the project to deliver the tool.

1.4. Bridging the science and policy gap?

The results of the survey evidenced the role played by research in DSS implementation in the real world. One can easily say that the adoption of a DSS tool by a potential end user, who is not involved in a research activity, is, to say the least, occasional. Therefore, even assuming that more effective dialogues between the science and policy spheres provide the ground for more effective DSS tools in the future, one of the main issues for future efforts in the fields of training and capacity building is the crucial role of mediators to encourage intended end users to adopt research outputs.

Indeed, science has been increasingly called to inform environmental policy making. Appeals to provide "useful" knowledge, i.e. one with direct policy implications, is a fundamental ethical principle for scientists. At the same time however, the dominant authority of science as the most privileged source of knowledge is being increasingly challenged. Moreover, it is crucial to realize that science and policy making, despite their interdependency, are rooted in different cultures and embodied in distinct frameworks of values, incentives and concerns. These differences have frequently led to frustrating experiences at the interface between science and policy.

Section 6 analyses the known factors of DSS success or failure based on the evidence of the international literature. Despite their crucial importance, the identification of DSS success factors and their measurement is a difficult task, since the development and application of DSS entail multiple potential benefits. The unambiguous detection of DSS failure is at least as difficult as the measurement of its success. From the experiences gathered so far it appears clear in general that the process of policy making is at least as important as its outcomes. Therefore, one important criterion is the degree of change to the usual management introduced by the implementation of the DSS. This could have a dual meaning, since an acknowledged limiting factor is represented by the resistance of managers to changes in conventional practices.

Box A: List of recommendations described in Section 7

Phase A: before the development or acquisition of a DSS tool

(1) Investigate and describe the problem at hand, the resources available and the data issue
(2) Identify the actors involved in the decision and explore the social context
(3) Understand the institutional and normative context
(4) Identify possible constraints
(5) Arouse users' interest and initial commitment
(6) Identify and clearly communicate reasonable expectations
(7) Decide whether or not a DSS may be useful for the purposes of the case

Phase B: the development of the DSS tool, or acquisition/adaptation of existing ones

(1) Involve end users in the DSS development throughout the process
(2) Define a clear strategy and work programme and include quality assurance
(3) Adapt tools to the users' needs and not vice-versa
(4) Refine users' requirements during the development phase
(5) Assure flexibility
(6) Accurately manage and communicate uncertainty

Phase C: DSS implementation and application in the decision case

(1) Provide a coherent methodological framework in which the DSS tool should operate
(2) Provide effective documentation of the limitations of the results provided
(3) Provide adequate documentation and support materials all together with the DSS tool
(4) Train users
(5) Exploit the full potential of the tool in supporting the whole process
(6) Provide the basis for maintenance and further development
(7) Adopt strategies for dissemination and technology transfer

1.5. The guidelines for DSS development and implementation

The final part of the report (Section 7) includes the Guidelines for the development, implementation and application of DSS tools. That section includes a series of recommendations that have been developed to increase the probability of future successes in DSS developments for the practical implementation of the IWRM principles. They have been organised according to a generic temporal sequence, by identifying three main phases:

1. the phase prior to the actual development or acquisition of the DSS tool;
2. the phase of development (in case of new tools to be implemented) or acquisition/adaptation of existing ones;
3. the phase of implementation and application in the decision case.

The most important messages and keywords to be extracted for the Guidelines are:

- accurate preliminary exploration of the problem and identification of actors involved;
- framing of the process and the DSS tool within the existing institutional setting;
- early involvement of end-users;
- match between DSS requirements and data availability and local knowledge;
- match between local practices and the DSS procedure;
- flexibility;
- communication within and outside the group of users;
- documentation;
- training and capacity building;
- dissemination and maintenance of the tools.

Details about the results of the DSS and questionnaire surveys care reported in the Appendices.

2. INTRODUCTION

2.1. Preamble

There are many different understandings of what a DSS is, what it is composed by, what it does (or should do) and how. Many different definitions exist and we prefer to avoid proposing a new one, letting the readers develop or keep their own ideas. The concept is indeed usually related to a computer-based tool, which is surely one important component, but more and more DSS is intended as a broader combination of the tool(s) and the process of structuring problems and aiding decisions.

Decision Support Systems (DSS) pervade all domains of water management (e.g. water allocation, flood prevention and forecasting, reservoir management) for a variety of reasons. In general, we may say that researchers are attracted by the capacity of DSS to convey scientific, transdisciplinary knowledge in an accessible format to policy and decision makers.

In an idealised view DSSs act as mediators between science and policy/decision making and as catalysts of trans-disciplinary research. Again, in an ideal situation, DSS tools facilitate dialogue between policy makers and scientists and both groups benefit equally from mutual learning. In the light of increasingly complex and interconnected environmental problems, the science sphere is increasingly called to inform (and improve) actual management and planning practices and scientists are requested to produce “useful” (i.e. applicable context-sensitive) knowledge.

DSS have been developed for over three decades with the purpose of replying to those calls. Unfortunately, DSS are seldom used for the intended purpose due to the misunderstanding of the motivations and incentives leading to DSS development. Even the term DSS itself is a catchword, having different meanings for different people, and covering different interests.

Different situations can be observed in the various application fields, but as far as DSS in the water management sector is concerned, one may easily say that we have already passed the typical initial phase of euphoria and we are now quite often in the disappointment phase, which may be followed by either abandonment or realism (Matthies *et al*., 2007). The question arises then, whether realism could allow us to make proper and effective use of – improved – DSS, or whether abandonment should be preferred. We will not provide a definitive answer, but we will identify a set of best practices to be implemented with realism, to provide the ground for more effective future developments and applications. Moreover, in order to gain more insights on that question, a questionnaire has been specifically designed and disseminated among DSS end users. The survey conducted focused on a selection of 10 recently released DSS tools and was mainly targeted to the products of European funded research. Neither the selection of DSS nor the information collected through the questionnaires are intended as representative samples of the universe of tools and application cases. The wide range of issues addressed, the diversified typologies of tools, the varied application contexts, are some of the reasons why a comprehensive and representative assessment would have required a whole multi-annual research project.

Right from the beginning of this report it is worth mentioning the difficulties encountered in identifying DSS tools used outside the development context and/or by users distinct from the software developers.

We will examine in detail the theoretical and terminological issues (see Box 1 for some details). Throughout the report the term DSS is used as a synonym for a wide range of tools (e.g. planning support systems, expert systems, etc.) which may be differentiated elsewhere, sometimes for good reasons. The issues addressed in this report are to a large extent similar for all the tools and the variety of meanings associated with the term DSS, which in this case may be seen as an advantage rather than a source of frustration.

Box 1: A bit of DSS history and terminology

The concept of DSS emerged in the 1970s when it was proposed for computerised systems providing assistance in dealing with semi-structured and unstructured problems. Gorry and Scott-Morton (1971) defined DSS as an interactive computer based system, which helps decision makers utilise data and models to solve unstructured problems. Kenn and Scott Morton (1978) proposed a similar definition, stressing the ability of DSS to couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. Over the next thirty years, new issues such as the increasing severity of environmental problems and growing conflicts in the exploitation of natural resources have added new challenges to DSS development. Due to the rapid advances in computer science and related research fields, the boundaries of DSS have expanded such that the understanding of what a DSS is (or might be) has become less apparent. According to Power (1997), any system supporting decision-making, including executive information systems, executive support systems, geographic information systems, online analytical processing and software agents, may be called a DSS. More recently, emphasis was placed on the multi-perspective exploration of problems (Shim *et al.*, 2002) and on shifting the target from semi-structured or unstructured to "wicked" problems (Beynon *et al.*, 2002; Courtney, 2001; McCown, 2002; Rauscher, 1999) The ambiguity of DSS definition has been discussed by several authors (e.g. Keen, 1981), some of whom go even further by viewing DSS as having matured to the point where they have lost their identity and became part of the mainstream field of management information systems (Carlsson and Turban, 2002).

2.2 What is a DSS tool?

In Box 1 we refer to several definitions of DSS, each of them is defensible in a specific context. The most common definitions refer to DSS as a computer-based tool, a higher form of information system (Keenan, 1998). When asked to explain with their own words what they refer to as a DSS, many developers point to a set of rules, tips or methods. As stated above, currently DSSs are quite often intended as the combination of the tool(s) and the process of structuring problems and aiding decisions.

Many DSS consist of simulation model(s), and/or of techniques and methods for decision analysis. Models' roles are almost as diverse as the uses and modelling paradigms employed. The variety is comprehensible, given the critical importance of models as instruments for scientific investigation and policy making (Morrison and Morgan, 1999; Pielke, 2003). In general, models can be used to (i) measure and represent; (ii) describe structure, behaviour and pattern; (iii) reconstruct past or predict future developments; (iv) generate and test theories and hypotheses; (v) surface, encode, transfer, evaluate and interpret knowledge; (vi) guide development and assessment of policies; and (vii) facilitate collective learning and settlement of disputes (Beven, 2002; Jakeman *et al.*, 2006; Morton, 1990). Decision analysis (DA) helps to avoid biases in judgement and to make decisions more compatible with normative axioms of rationality for situations involving multiple, conflicting interests and beliefs. The trade-offs or preferences are value judgements, which are frequently not observable and must be revealed or approximated. Such uncovered preferences are context-specific and depend on the description and framing of a problem, and how the questions are formulated. For example, to assess the environmental costs of irrigation, one must consider the value of wetlands and riverine ecosystems deprived by water abstraction.

There is a broad agreement about what DSS are expected to do: in general terms, DSS are set to aid decisions and structure problems. DSS are expected to explore multiple perspectives of the problem at hand; enhance decision makers' insight into the problem drivers and policy outcomes; and facilitate communication and knowledge transfer between the actors involved in or affected by the decision. Therefore, the DSS role should be intended as tools for supporting the process of decision making much more than tools to provide answers to decision makers' questions. This is particularly true also because DA methods act as "lenses" through which the policy problem is viewed, lenses may have different curvatures and thus different DMs may (frequently do) lead to different conclusions.

The fact that alternative models or, for instance, different decision rules in multi-criteria analysis, may lead to different solutions of the problem at hand is a crucial issue for DSS tools. Adequate quality assessment procedures guarantee only to some extent that the methods and tools adopted are theoretically and methodologically robust. In some cases different approaches, all suitable for the issue in question, still provide contrasting results. This problem should not be neglected and should support the advisability of testing – as far as possible – alternative approaches in the same case.

Box 2: Glossary of terms adopted in this report

Decision: The choice of one from among a number of alternatives; a statement indicating a commitment to a specific course of action.
Decision maker: An executive person or group responsible for land-use policy, action and allocation of resources.
DSS developer: The researchers or consultants directly involved in the development of the DSS tools, for their design, coding, etc., in response to specific needs of one or more potential end user(s).
End user: Those policy-makers, consultants, technical staff or researchers, involved in DSS application, and distinct from the tool developers. The potential users, which contributed to the design and implementation of the system during the development time, were also considered.
Knowledge: This term is used to mean the confident understanding and mastery of a subject. In the present context we refer to k. as what is known by qualified individuals (expert k.), or by people in a given community (local k.). Knowledge acquisition involves complex cognitive processes: perception, learning, communication, association, and reasoning.
Model: A simplified representation of reality used to simulate a process, understand a situation, predict an outcome, or analyse a problem.
Policy vs Science: When distinction between the two spheres is made, we intend to identify within the first one the community of people belonging to private or public bodies formally sharing the burden and the power to take decisions, while in the second we include all the people (researchers, technicians, consultants, et.), who are not directly involved in the decision itself, but (may) provide technical and scientific support to it.
Policy maker: A person with power to influence or determine policies and practices at an international, national, regional, or local level.
Stakeholders/Actors: Those who have interests in a particular decision, either as individuals or as representatives of a group. Including people who can influence a decision, as well as those affected by it.

The unstructured nature of many problems related to natural resources management may be caused by: (i) different ways in which the involved persons see the problem; (ii) complexity of environmental systems, their dynamics and interconnections; (iii) identification and assessment of actions; (iv) modelling the consequences of a different course of action; or (v) ambiguous and conflicting objectives. The solution of one aspect of an unstructured problem may reveal another, more complex problem. In such situations, the process of solving a problem is the same as the process of understanding its nature; they are mutually concomitant. Only concrete solutions which have been formulated and analyzed provide a deeper insight and understanding of what the problem actually is.

Many authors consider DSS as a technology. Environmental management, as perhaps no other field, relies on a huge amount of information (e.g. GIS and remote sensing data, time series of precipitations). To store, visualize and analyze these data, the pure cognitive capability of humans is of limited use. Besides, DSS help to avoid biases in judgement and make decisions more compatible with normative axioms of rationality for situations involving multiple, conflicting interests and beliefs. To qualify for DSS, the tools are expected to turn information into knowledge. As computerized tools, DSS are surrounded by a number of issues related to technology, its diffusion and acceptance. Seeing DSS' limited success as a failure of technology tips into a number of issues including personal aspects (e.g. prior expectation, education, value and belief of intended users and impact on their job); technical aspects (e.g. user interface, performance, reliability); institutional aspects; management processes that DSS are designed to aid; or any combination of the Above. It is this viewpoint which prompts increasing frustration, negative attitudes towards DSIT and abandonment.

However, hardly any DSS research project aimed at technology in the first place. DSS were supposed to connect disciplinary knowledge and solve methodological differences, in other words, the motivation to develop DSS was to facilitate integration and transdisciplinary research. For DSS to fulfil their task, i.e. aid policy making, a number of quite distinct issues come into play. Superficially these issues may be seen as problems of data collection (different data are connected for different spatial or temporal units), the nature of data (e.g. qualitative versus quantitative), or as a lack of common terminology (e.g. a wider range of different interpretations of uncertainty). The most difficult issues to overcome, however, are problems of epistemological nature, i.e. what is recognized as knowledge, for what purpose, embedded in wider disciplinary differences. Methodological differences between social and natural sciences are notoriously known but significant differences exist even within a single discipline (e.g. ecological economics and environmental economics). The perspective of DSS as a catalyst of trans- or interdisciplinary research provides different views on the success and failure.

3. METHODOLOGICAL BACKGROUND AND LITERATURE REVIEW

Water resource management has attracted a particularly vast level of attention in the recent decades. This is partly because of the fundamental value water exhibits for sustaining life and development. Water is a finite, depletable, nonsubstitutable and unevenly distributed resource with a unidirectional flow pattern, which incites conflicts and prompts a number of threats such as floods, landslides and erosion. Most of the problems handled by water resource management have the characteristics of unstructured problems. To ensure an efficient allocation and protection of water, a holistic (integrated/comprehensive) management based on the principles of the ecosystem approach was endorsed by a broad scientific and policy community. Such a management favours pro-active, non-structural and demand-side interventions. Yet, the integrated ways to resource management require a trade-off to be made between different, often mutually exclusive interests and values, which aggravate conflicts (Walker *et al*., 2001). As the water resource conflicts become more complex, more accurate and comprehensive evaluation of management activities is required. The process of policy making has increasingly favoured interdisciplinary, pluralistic, and inclusive methodologies, with scientists participating alongside other stakeholders in deliberative decision making, participatory assessment or group model building.

To support the implementation of the new water policy introducing the principles of an integrated, river basin management, the European Commission has dedicated a key action under the 5th Framework Programme (FP5, 1999-2001) to issues related to sustainable management and water quality. The WFD principles like transboundary management of water issues; holistic, cross-disciplinary management regimes; public involvement and application of economic instruments such as water pricing and cost recovery required further research before becoming operable in different conditions across the EU countries. The EU work programme highlighted the "social, economic and cultural pressures" on water resources, causing threats (to the environment) and increasing conflicts between water uses. It emphasised the need to improve the knowledge and technologies supporting a "rational and sustainable" management of water resources which requires policies, tools and methods able to govern interwoven environmental, social (institutional) and economic systems in their full interaction at the river basin scale.

The DSS developed in the context of EU funded research (e.g. MULINO, TRANSCAT, MERIT, GOUVERNE) facilitate WFD implementation by (i) making for effective data management, (ii) providing a suitable environment for the implementation and integration of environmental models, and (iii) aiding social learning processes among stakeholders involved or affected by the measures to achieve the WFD's objectives. Within the 5th Research Framework Programme (5FP) altogether 150 projects were funded under the water key action with the total budget amounting to 244 mil Euro. 43 projects or 68.6 mil Euro were dedicated to integrated management methodologies and tools at catchment/river basin scale. 7 projects with a budget amounting to 11.2 mil Euro were funded under the priority 1.1.3. "Operational management schemes and decision support". Although pursuing distinctive objectives, all the projects paid attention to integrated catchment modelling, risk management, quality assessment, optimization and responses of river basins to policy changes (EC, 2001).

A review of existing DSS was carried out in a number of projects (e.g. NEWATER, AQUASTRESS, FLOODSITE, NOSTRUM-DSS, WATERSTRATEGYMAN, CODES, TRANSCAT and MULINO). The reviewed tools related to each project's specific objectives and application conditions. Altogether the review encompasses more than 150 tools and DSS application reports (see also Annex I). Also, what was considered as a tool varied considerably, including conceptual tools and process based tools facilitating learning. Most tools addressed in detail, however, were computer-based. Different evaluation criteria have been used in different projects to assess system applicability (see Box 3). Only a few reviews addressed the lack of implementation success in more detail. The variety of evaluation criteria employed suggests that the evaluation is context-dependent and experiences from one case may be only poor indicators of performance for other cases (Jeffrey *et al.*, 2005).

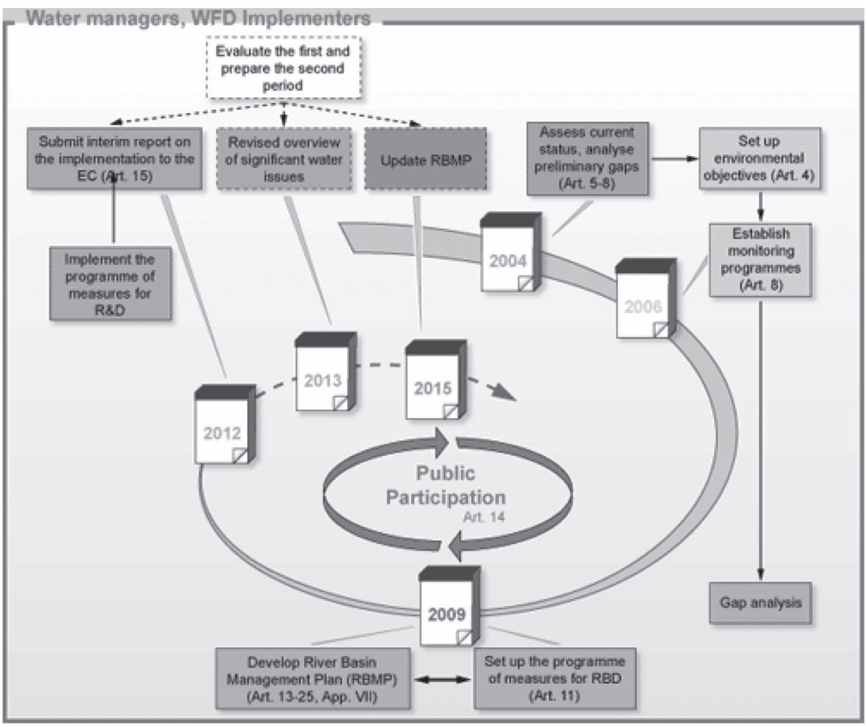

Figure 3.1 The Water Framework Directive Implementation Plan

The DSS developed to assist water resource management are mostly model-driven DSS. DSS help to understand feedback among processes operating at different spatial and temporal scales (National Research Council, 1999). Emphasis is placed on hydrologic models accompanied by environmental assessment and/or socio-economic evaluation. The application of models is referred to both the environmental models aimed at reconstructing the reality, and decision models constructed to compromise conflicting objectives and to mitigate the expectation of different actors. A DSS for water resource management typically integrates multi-source geographically referenced data and data management systems, a variety of models and optimization procedures within a customized user interface. Additionally, pre- and post-processor utilities may facilitate data exchange between the implemented models. A set of other functions may assist in data preparation and management tasks. An educational component may assist the decision maker to understand the data and implemented models. The systems may support graphical (network-based) ways to define water resource systems or are based on (or extendable by) a commercial or public domain Geographic Information System. The multi-source data bases may include environmental (hydrological, climate, soil, and meteorological) and socio-economic data (demographics, economic development etc.).

The variety of models includes hydrologic models (run-off, sediment, flood routing, flood inundation, reservoir, point and non-point pollution source models, etc.), physically-based simulation models (e.g. soil erosion, agricultural-chemical transport, crop-soil-water interaction, nutrient and pesticide transport models), socio-economic and environmental impact assessment models (e.g. crop assessment model), management and optimization models (linear programming, dynamic

Box 3: Evaluation criteria for applicability of DSS in specific contexts

The identification of DSS success factors and their measurement is not an easy task. This is because the development and application of DSS entail multiple tangible (e.g. better outcomes) and intangible benefits (e.g. mutual learning, trust and cooperation). For more detail see section 6. Here we refer to some measures and criteria of success and failure applied in the context of various international projects this review draws on.

CoDES review (urban water management) (Kapelan *et al.*, 2005)

1. Level of integration
2. Scenario modelling support
3. Policy/intervention options
4. Sustainability criteria and indicators
5. Impact assessment

6. Use of ranking/optimisation technologies
7. Risk/uncertainty modelling
8. GUI and visualisation
9. Support for different spatial/temporal scales
10. Support for group decision making
11. Input data requirements
12. Computational efficiency
13. Calibration/validation
14. How easy/difficult is it to use the tool.

WaterStrategyMan review (water management in southern European countries) (ProGea, 2004)

1. Graphical user interface, connected to a geographic information system;
2. Framework of indicators covering a range of different topics such as water quantity and quality, climatic change, demography, sustainability, cost components, and environmental water demand;
3. Ability to develop scenarios, comparable with MCA;
4. Economic analysis

AquaStress review (water stresses in Europe) (Jeffrey *et al.*, 2005)

1. Cost: purchase price, development costs, demonstrated return on investment, cost of use, training costs, licence and maintenance costs
2. Integration: level of component integration, potential for interfacing with other tools, reuse of components, platform support, interoperability across operating systems
3. Model outputs: computational accuracy and efficiency, integration of results across phenomena and domains, platform robustness, repeatability of results, easy of understanding results, verifiable audit trails, accessible peer reviewed literature for performance and case study applications
4. Flexibility and adaptability: scenario generation, exploration of intervention options, present information in multiple formats for different stakeholders
5. Ease of use: easy of links to other knowledge bases, quality of user interface, functionality, tool accessibility, different language supported

programming, multiple criteria decision making, genetic algorithm, risk assessment, etc.). The goal of the executive interface is to provide a concise and clear presentation of the data and models and should bridge the gaps in model understanding.

DSS have been developed for a variety of situation contexts which differ significantly in pursued objectives, required functionality, modelled processes and phenomena, spatial and time scale, and supported users. Generic DSS, i.e. systems built upon methodologies and models which are applicable to a range of different management situations (e.g. AQUATOOL, RIVERWARE, WATERWARE, ELBE DSS or RAISON. AQUATOOL, TWOLE and RIVERWARE), support planning and operative decision making in complex basins, including multiple reservoirs, aquifers and demand centres. WATERWARE on the other hand, addresses a range of issues like environmental impact assessment and evaluation of measures against pollution. RAISON (Booty *et al*., 2001) represents a kind of generic software tool for rapid prototyping and practical implementation of environmental DSS. The DSS like that described in (Lilburne *et al*., 1998) aim at problems related to the water quantity and help to improve water use efficiency. The problems addressed are typically irrigation planning problems and allocation of water resources between headwater and downstream users. Water quality issues are addressed by a range of DSS: WATERSHEDSS, MOIRA, EFDSS, BASIN, DEMDESS, DESERT, ELBE-DSS and EFDSS. The problems they deal with encompass the identification of water quality problems, integrated assessment of point and non point source pollution, selection of appropriate management practices etc. Assessment of impacts of changed land use or industrial, forestry, urban and agricultural projects on water quality and/or other environmental impacts is the goal of systems like WAMADSS, CMSS and GIBSI. Some DSS aim at more specific problems like optimal remedial strategies to restore radionuclide contaminated fresh water environments (MOIRA) or integration of a range of models of riverine ecology (EFDSS). Real-time river basin flood control and reservoir management is supported by the DSS like SDSS (Shim *et al*., 2002) and (Stam *et al*., 1998). FLOODSS aims at forecasting catastrophic events and at preventing and mitigating their effects on the environment. Recently, the Internet prompted development of a new typology of distributed DSS such as AQUAVOICE (Jonoski, 2002) or Transcat (Marsik *et al*., 2006). The development of DSS is facilitated by modelling frameworks, supporting modular model developments and re-use of existing model components such as ICSM and SME described by Argent (2006).

The benefits from the DSS development are not restricted to the final system and its suitability for the supported management processes. Research challenges associated with (or intermingled with) DSS encompass (i) investigation of how innovation makes it way to practical management processes, and how institutional arrangements can help to overcome the initial resistance and maintain commitment to pursued changes; (ii) analysis of human capabilities to comprehend processes and cause-effect relations in complex worlds; and (iii) study of how technological progress and advanced computing algorithm are able to overcome the cognitive limitations. In the water resource management, DSS field is linked to integrated assessment and holistic regime to water and related land and soil resources. Consequently, the assessment of DSS' success cannot be reduced to a single measure. The conceptual diversity inherent to the DSS term and the range of benefits from the DSS development process has to be taken into account.

The computer modelling aimed at assisting water resource management is becoming more sophisticated and the gap between specialized knowledge of the DSS developers and application of this knowledge in decision making is more apparent. The water DSS development domain is challenged by the need to manage, if not to hide, the models' complexity for developing effective interfaces with the users and to make model appropriateness and decision procedures transparent to the decision maker. This is further explained in Section 6 dedicated to DSS success and failure.

4. THE PERSPECTIVES OF DSS' END-USERS

This section aims at analysing some concrete cases of DSS tools developed in support of the Water Framework Directive, by EU funded projects or National projects. A comprehensive review has been carried out to end up with approximately 10 DSS to focus on. After a preliminary categorisation of the tools aimed at selecting samples belonging to different typologies, the main criterion adopted for the final selection was their actual present or past use by potential end users. DSS developers of the selected tools were contacted to know whether end users would have been available to fill in the questionnaires (Annex III). The review scope was to acquire insights into actual and potential users' needs, expectations and satisfaction, during the tool development and application. The analysis allowed a specific investigation on successes and failures of tool application from a user's point of view. In case of tools still under development the expectation on the tool's usefulness and required functionality were assessed.

4.1 The review

A preliminary list of 60 tools (see Annex I) was developed from several sources, such as reports of EU funded projects (i.e. (FEEM, 2005; ProGea, 2004), the technical report on DSS (McKynney, 2004), the CORDIS online database (http://cordis.europa.eu/search/index.cfm). A list of 15 tools likely to be considered in the review have been identified and included in a draft list to be able to end up with a sample of about 10 tools. The preliminary contacts with DSS tools' developers allowed to identify their willingness and interest to be involved and, as previously mentioned, the probability of establishing direct contacts with end users, which was considered a pre-requisite for the inclusion in the survey.

Some tools had to be excluded from the review as they were still under development, and/or never transferred into the public domain and/or never applied. DSS tools for which the developers provided their availability and identified a list of at least two users are in the final short list.

The search for the availability of end users of the tools and the interactions with DSS developers suggested a series of revisions in the original list. TWOLE was added as a distinct product related to the MERIT DSS, while the KerDST “Deliberation Support Tool” (DST) was selected as a representative of a group of tools first developed in the GOUVERNe project. Finally, the WFD-EXPLORER was suggested as a suitable example for the products developed at Delft Hydraulics.

End users suggested by developers were contacted via e-mail for the compilation of the questionnaire reported in Annex III, designed to collect users’ perspectives on the tool’s development, acquisition and application.

Box 4: Main characteristics of the DSS tools examined

Tool	Domains				Sectors			Support provided				Users		Technical features		
	Surface water	Groundwater	Socio-economy	Ecology	Water management	Land	Urban	Communication	Decision analysis	Prediction of Policy Outcomes	Identification of Options	Water Authority	Stakeholders	Multilingual	Operating system	Web Based
CatchMODS	X	X		X	X	X				X		X				
Elbe-DSS	X		X	X	X	X	X	X	X	X		X	X	X	MsWin/Xp	
KerDST			X	X				X	X		X	X	X	X		
MERIT DSS	X	X		X				X	X	X	X	X	X		MsWin	
MONERIS	X	X		X	X	X				X		X			MS-xls	
Mulino DSS			X	X	X	X	X	X	X	X	X	X			MsWin 2000	
RiverWare	X	X	X	X	X			X	X	X	X	X			UNIX/Ms Win	
TwoLe	X		X	X	X				X			X				
WaterWare			X	X			X		X	X		X			MsWin	X
WFD-Explorer				X	X			X				X	X	X	MsWin Xp/Nt	
WSM DSS			X	X	X		X	X	X		X					

4.2 The selected tools

To contemplate the variety of DSS typologies, a wide range of tools' types and functions were considered. These included software libraries and tools specifically tailored for developing a DSS for IWRM (i.e. RIVERWARE), single models (i.e. MONERIS), or tools provided of several integrated models, a database and a user interface (i.e. ELBE-DSS, WATERWARE). The tools considered are presented in Box 4 and described through various features such as the domains and sectors considered, the kind of support provided, the type of intended users, and other technical characteristics.

An extended description of the selected tools is presented in Annex II. The tools' characterizations have been prepared through the available documents and investigate the primary scope and domain of the various tools development and application, some features of the technical design, the kind of support provided. Other information included concern the distribution, maintenance, users and applications, documentation and development. The descriptions have been edited by the DSS' developers.

4.3 The questionnaire

The questionnaire is divided in four different sections (see Annex III). In the first section the questions focused on the motivations and the scopes of the development, acquisition, and application of the DSS. The next section requires the specification of the role assumed by the user during the system's development and of the conditions of usage. Gathering information on the concrete experience, use, implementation and maintenance of the system was the target of the third part of the questionnaire. This part investigates in particular the impacts on the policy making process after the tool's application. The final part of the questionnaire has been dedicated to the elicitation of benefits and satisfaction resulting from the use of the system and its different components.

A first version of the questionnaire was distributed and tested at «EUROPE-INBO 2006» 4th European Conference held in Megève (France) the 20th-22nd of September 2006. The comments received from the participants on the structure and contents of the questionnaire were taken into account for its dissemination to the intended users. Thanks to the indications of the selected DSS developers, in total 40 questionnaires have been distributed to end users and 26 replies have been collected. We ascertained a willingness to cooperate in just a few of the target persons. Receiving their feedbacks was thus a demanding task. The following paragraphs are the result of the filled questionnaires' elaboration. The details of the answers given by the 26 respondents are presented in Annex IV. The answers to the free questions are faithfully reported, meaning that the language check was not carried out on this part of the text.

4.3.1 *Development, acquisition and application*

Most of the users reached were at their first experience with a DSS and the main motivations a for the development and acquisition of the system were acknowledged to be a proposed partnership with research institutions, but also emerging needs or inability of the previous management system to approach increasingly complex decisions. The main objectives targeted with the development and acquisition of the DSS were the opportunity to facilitate stakeholders' involvement in the decision making process, to identify alternative policy options and to gain a better understanding of the problem at hand. The fulfilment of specific regulatory obligations and requirements, i.e. the implementation of the WFD, was also pointed out as a target of the tool application.

The majority of the users contacted couldn't say whether the implementation of the DSS imposed changes to the traditional decision making process in their institution (i.e. the answer to the specific question was "Neither agree nor disagree"). This result can be explained by considering that an important part of respondents was involved in the project's case studies for tool testing. In fact, the questionnaire was rarely filled in with reference to applications for concrete decision making processes. Nevertheless, a remarkable portion of the respondents affirmed that a change occurred in the process due to the tool's adoption.

Generally, the developed DSS have been integrated with other software previously used and the integration itself was judged important for the decision to develop and acquire the system. Most of the DSS considered incorporate a GIS and seldom a database management system or a model.

4.3.2 *Personal background*

Most of the respondents reached are specialised in the field of water planning and management; just a few are experts in modelling. In general they are advisors or policy makers, although a significant part of the respondents are researchers or in close relation with the academic world.

The end-users' involvement concerned mainly the identification of their current and potential needs and, secondly, the test and evaluation of prototypes during various phases of the development. It emerges how end users' involvement occurs usually at the very initial phase related to the specification of the problematic and at the final phase of tool testing. Adaptation and adjustments to the user's needs through the whole process are often missing.

MONERIS and RIVERWARE are systems developed and used for at least 10 years and are generally applied on a daily basis by end-users. Systems like WATERSTRATEGYMAN have been developed more recently, i.e. 2002/2003, and are used on a continuous basis. Other DSS are used but only occasionally.

ELBE-DSS and WFD-EXPLORER are still under development, but they have already been applied in the context of pilot case studies.

Most of the users reached interact with the system directly from their PC. The respondents' opinions on the difficulty in becoming familiar with the system were discordant. Indeed, the perception of the system's complexity varied more according to the personal background and the application context, than on the type of tool. Moreover, most of the respondents don't perceive their role in the decision making approach changing because of the adoption of the DSS. This can be explained, again, by considering that most of the tools included in the survey were developed and applied by research projects.

Box 5: Evidences from the survey in brief

Quite often research projects' products are built till they reach the state of prototype and are not further implemented and delivered in a commercial setting. Insufficient cooperation between the project's partners has been singled out as the main reason of failure in the attempt to carry on the project till the acquisition and application of the tool. This is often the case of tools developed in the frame of EU projects, aiming more at research objectives and confined to the experimental phase. For this category of DSS tools it has been hard to identify and get in contact with the intended end-users.
In those cases in which end users were involved in the research projects, they often belonged to administrations in the water management sector. It appears that their involvement is problematic for various reasons: their motivation to be involved in studies marked by an investigative and exploratory intent, the difficulties in coordinating the timing of the project with the real world case timing, when decision processes are considered; the reluctance for being officially bound from the project results in future policy choices.
The lessons learned and principles tested in the environment of these projects have been further implemented by subsequent and ongoing projects. This allows eventually to characterize the subsequent framework programmes, e.g. FP4 "Technocratic DSS", FP5 "DSS tools presented to potential users", FP6 "DSS developed with potential users".

4.3.3 Implementation, use and maintenance

In the users' opinions, the adoption of the DSS was useful in a broader context, not only to provide information on the choice of a policy, but to facilitate the planning and learning processes among the actors, contributing to finding a compromise among different expectations and interests. It has been pointed out how some tools are designed to meet regulatory obligations, giving insights for the solution of the problems encountered, especially during the implementation of the WFD. Apparently, the majority of the selected tools are still maintained and further developed.

Re-use of the system did not impose great difficulties to the users, but training and assistance were considered as a fundamental prerequisite for the successful application. Similarly, another important condition was the presence of adequately trained individuals within the institution.

4.3.4 Benefits and satisfaction

Section D provided insights in the perceived benefits and satisfaction level of DSS users. The vast majority of respondents either agreed or strongly agreed that the implementation of DSS improved the pre-existing approaches (D1). The user interface and functionality of the databases were both perceived as sources of high satisfaction for the DSS used (D2) and as the most critical components (in the open questions) for an effective use and application of the system.

An incomplete database and the lack of available data, the complexity of the various modules and the perception of the model as a black box are examples of the system's limitations cited in response to D3 and D4. The adoption of too short-term time scales, in comparison with the regulatory requirements, and the non-availability of the system as open source software were also valued as a relevant limitation for the system's adoption.

When the components of the system were questioned by the stakeholders, the disputed points mainly regarded the quality of the input data, the complexity of the user interface and hidden data's uncertainties.

The analysis of responses to D4 (future recommendations) is very interesting and the development of more friendly user interfaces appears again as the hot issue for the future. The recommendations for the improvement of similar systems in the future are summarized in Box 6.

In conclusion, having remembered the difficulties encountered in identifying a sufficient number of cases of tools that were utilized by users distinct from the developers, and that most of the cases available were still to some extent academic exercises, a general optimism emerged from the end users' experiences, related to the potentialities DSS tools have to support and improve the decision making process in water resources management. Prerequisites for more effective future developments seem to be an improved user-friendliness, and, related to that, the involvement of users in all phases of the tools' development and by providing adequate training support during and beyond the end of the development phase.

Box 6: Users' recommendations for DSS development

- About the user interface: more user-friendly interface to improve handling of model inputs and outputs /make the user-interface clearer for communication with stakeholders/better interface, more flexible data base interface/implementation of GIS interfaces.
- To ensure an adequate availability of data, improvements should mainly be made at the European scale, to provide consistent, homogeneous and reliable sources of input data.
- Technical follow-up of the project has to be carried out in a more careful way.
- Stakeholders' opinions have to be taken into account
- The use of the tool for the project's purposes and further investigation allowed to understand the difficulty of adapting such a model to suit everyone's needs. In fact, it seems that each decision support system tool should, ideally, be adaptable to different scales of analysis and databases. Open access to source codes should help.
- Regular training on new features, if useful, should be planned.
- This technology is expensive to develop and maintain. Partnership between larger Institutions is often critical to fund the next generation of this type of tools.

5. REVIEW OF POTENTIAL END USERS' NEEDS THAT COULD BE MET BY DSS TOOLS

DSS are built to meet users' needs which should be, by definition, related to a specific decision issue. In a narrow view the users' needs stem from the institutional role and the responsibility assigned to the users, or better, to their institutions. For example, the role of river basin authorities may be to develop river basin plans and manage water resources accordingly, monitor water quality and quantity, release warnings in cases of expected floods or droughts etc. For example, after the devastating tsunami in 2004, the competent authorities decided to develop a tsunami forecasting system to allow early warning and the implementation of preventive measures.

In some cases developing DSS to match institutional tasks and functions can be straightforward. In other cases the available knowledge may not be sufficient. The required information may not be available at all or not in the required form (e.g. for a specific spatial or temporal unit/scale). For example, in the absence of groundwater quality data the river basin authority may enforce decisions regarding the groundwater protection or management, but these decisions may not be optimal and can be contested. In general, users' needs can be related to all impediments preventing users from making decisions based on sound knowledge and management techniques.

Sometimes the required knowledge is not available because of the lack of scientific understanding or the variability of the factors which influence the specific situations. In these cases the investment, e.g. in the monitoring networks, does not improve the knowledge on the basis of which the decision needs to be made. What is required is an improved scientific understanding of the underlying phenomena or an introduction of governance regimes which can cope with the intrinsic uncertainties and which are able to obtain a wider consent among the affected actors. Therefore, users' needs can also refer to scientific progress (e.g. interdisciplinary research about the consequences of climate change) or to the effectiveness of institutional arrangements (e.g. ability to cope with conflicts).

Science has been increasingly called to inform environmental policy making. Appeals to provide "useful" knowledge, i.e. one with direct policy implications, is a fundamental ethical principle for scientists. At the same time however, the dominant authority of science as the most privileged source of knowledge is being increasingly challenged, and a greater openness and dialogue between all knowledgeable parties is called for. It is crucial to realise that science and policy making, despite their interdependency, are rooted in different cultures and embodied in distinct frameworks of values, incentives and concerns. Frequently, these differences have led to frustrating experiences at the interface between science and policy.

Box 7: Key Issues of WFD and Research Needs

To assist in the implementation of the WFD, the Water Directors initiated a study on the Key Issues of WFD and Research Needs. The study intended to produce a list of specific topics as input for the research community. However, neither water managers nor researchers were able to provide lists of topics in sufficient detail to match them (CIS, 2005). Nonetheless the study uncovered a number of issues, some of which are relevant for the DSS field. Frequently, the required data are either not available at all, or not in the required format or aggregation level. A variety of methods and techniques, e.g. for monitoring of water quality, are applied across various countries in international river basin districts, sometimes yielding not easily comparable results. In a number of cases, adequate measures (e.g. the pesticide directive) to comply with the WFD objectives can be applied only at EU level (CIS, 2005). Fundamental gaps in the understanding of ecological processes and the human impact on such processes were highlighted. The study recommended a closer, face-to-face collaboration between the research teams and the policy makers involved in the WFD implementation.

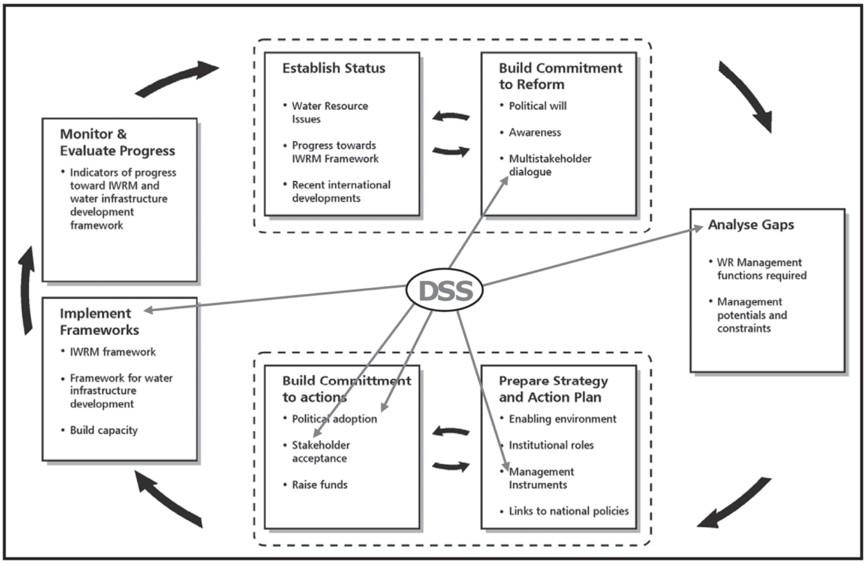

Figure 5.1 The IWRM process and the role DSS could play in supporting the implementation of the cycle. Figure modified GWP-TEC (2004)

To overcome the science – policy gap, many have argued that policy (or action) related research differs from mainstream science in several aspects: it is action-oriented (in the sense that the implementation concerns are a part of the research), integrated, value-committed (as opposed to 'value-free'), situation-specific, operating on the long term and sensitive to the lack of commitment of involved actors (Meppem, 2000; Shi, 2004). In other words the way science informs policy-making needs to be re-thought. The re-definition of relations between science and society includes release from disciplinary and institutional rigidity; methodological pluralism (embracing ambiguity); surfacing one's own normative assumptions, values, motives, potentials and limits; and an engagement in ongoing dialogue (Muller, 2003). This has several important implications: first, scientists should be prepared to facilitate policy processes rather than to determine them; and secondly, the process of policy making is at least as important as its outcomes.

A fundamental challenge of policy-related research is the quality assurance of the whole decision process and its results. Many policies are afflicted with complex conflicts and quality assurance in this context has to take into account intangible and incommensurable aspects such as subtle changes in behaviour, level of trust, and changes in relations. Their weights and how they are translated into decision outcomes (more effective and efficient decisions) and in the decision process (more informed, inclusive and transparent decision making) are to a large extent specific to a given context, and thus hardly transferable. Therefore, the peer review which is the traditional means for assessing research quality alone is not sufficient. Other criteria have been proposed, including extended peer-community review or commitment to the accountability of researchers. For example, the hurricane forecasts of the National Hurricane Center in Florida include the names of researchers who developed them. However, the lack of generally applicable quality assessment criteria poses an important challenge to the transferability of the insights collected in policy related research.

Due to the central role of policy-making models for water resource management, the quality assessment of the simulation modelling process attracted a vast attention. HarmoniQua Guidance and Modelling Support Tool MoST (Refsgaard *et al.*, 2005; Scholten *et al.*, 2007; Scholten and Udink ten Cate, 1999) guides model development, monitors the progress done, and advises the modelling team on the basis of model journals, collected during the previous projects. To this end the modelling process has been broken down into five generic steps and forty-four detailed tasks, each further specified in terms of activities to be performed. The steps, tasks and activities have been completed with practical recommendations, further differentiated according to modelling domain, users' level of expertise, and job complexity.

6. DRIVERS OF THE IMPLEMENTATION SUCCESS OR FAILURE

6.1 Defining success

Despite their crucial importance, the identification of DSS success factors and their measurement is a difficult task. The development and application of DSS entail multiple benefits which make measurement of DSS success difficult. Many factors are likely to influence DSS success, but their importance may vary significantly according to situational variables. Very frequently studied factors of DSS success include (i) actual use and re-use of DSS by intended users, and (ii) user (perceived) satisfaction. The former indicates that the benefits from DSS usage were considered to be greater than the costs, especially in case of re-use. The latter expresses the level of the satisfaction perceived by the users as a consequence of having implemented the system. Obviously, these factors are not independent of one another, as a higher satisfaction can lead to its repetitive use and vice versa, see in (Finlay and Forghani, 1998; Wierenga and Oude Ophuis, 1997). Neither of the two factors analyses the changes in decision maker's performance achieved by using DSS, very difficult to assess on its own. The change itself should not be considered a priori as a positive indicator, first of all because change does not necessarily mean improvement and, secondly, because one recognised characteristic for the successful implementation of DSS tools is their ability to adapt to existing management approaches. Efforts required for changing usual management practices by the end users have been often identified as one of the main barriers to the uptake of the available DSS.

The DSS usage as expression of DSS success, being a twofold variable (is used, is not used) is criticised for its lack to further differentiate the systems used (Gelderman, 2002).

The pure subjective assessment of the DSS acceptance is also not unambiguous. Frequent usage of a system, familiarity with its structure and involvement in DSS building have been proven to increase the decision maker's illusion of control (Kahai *et al.*, 1998; Matthies *et al.*, 2007).

The unambiguous detection of DSS failure is at least as difficult as the measurement of its success. In many cases, even when DSS development was stopped or the system was not used by its intended users, essential learning processes took place. Newman (1999) refers to a case when the DSS has become obsolete because the end user has learned (by DSS using) its logic and was able to apply it on his own. Bell *et al*. (2001) refer to a similar situation when the decision makers, by using the DSS, were able to get detailed insight into the decision problem and understood their own preferences better, although the adopted solution differed from the solution proposed by the DSS. The examples show that if a DSS is not practically used or the solutions proposed by the systems are not adopted, it cannot be generally considered as a non-ambiguous criterion of the systems' success or failure.

6.2 Critical success factors

There is a large body of literature dedicated to the processes behind the acceptance of and resistance to DSS and technology in general, a selection of relevant evidences and references are presented below.

A number of typologies of critical success factors have been developed in management and computer sciences (Alter, 2004; Borenstein, 1998; Chen and Lee, 2003; Eicher, 1999; Finlay and Forghani, 1998; Gelderman, 2002; Harrison and Pelletier, 2001; Jiang *et al.*, 2000; Kahai *et al.*, 1998; Kamp, 1999; McBride, 1997; McHaney and Cronan, 2000; Newman, 1999; Nightingale, 2004; Palvia, 1997; Palvia and Palvia, 1999; Palvia and Chervany, 1995; Poon and Wagner, 2001; Santhanam *et al.*, 2000; Schultze and Boland Jr, 2000; Shaw and Edwards, 2005; Uran and Janssen, 2003; Wierenga and Oude Ophuis, 1997). These typologies distinguish between personal factors (such as prior expectation, education, value and belief, impact on user's job); technical aspects (user interface, performance, reliability) and the interaction of both (social content gain and loss before and after the DSS implementation), differing in the importance attached to these categories. Other categories frequently applied to study the DSS success include the external environment, the organizational aspects (e.g. changes in interpersonal relations) and the management processes that DSS are designed to aid. The role of some other actors has been reported as crucial for the DSS success (Finlay and Forghani, 1998): (i) DSS champions - managers who actively promote the DSS concept among the potential users; (ii) supporting political actors - people whose influence is needed to secure support for the DSS; and (iii) direct supervisor of the user - persons to whom the user is directly accountable. It is also practical to distinguish factors which raise commitment to a change (e.g. availability of technical and human resources, presence of a powerful actor inclined to support innovation) from those which maintain the commitment (e.g. early user's involvement, DSS prototyping).

Another class of approaches analyses cognitive aspects (cognitive styles of decision-makers) and their influence in accepting/resisting formal decision making and employed technology (Lu *et al.*, 2001; Chen and Lee, 2003; Barr and Sharda, 1997; Jiang *et al.*, 2000; Kahai *et al.*, 1998). Cognitive types are chronic motivations determining the initialization, course and cessation of information seeking and processing (Blais *et al.*, 2005). Cognition may influence perceived facts and behaviour tendencies (Lu *et al.*, 2001). Consequently, different people with the same belief may develop different attitudes and different people with the same attitude may develop different behavioural intentions. Different cognitive styles have been described to explain these phenomena. Blais *et al.* (2005) employed three cognitive style measures – the need for cognition; the personal need for structure; and the personal fear of invalidity. (Lu *et al.*, 2001) analyzed cognitive styles determined along information gathering (perception styles) and information evaluation (judgement styles), resulting in sensing/intuition and thinking/feeling cognitive styles. The emphasis on the cognitive modelling characterizes a new trend in DSS development. The cognitive DSS focus explicitly on decision maker's mental models, facilitating their enrichment, validation and supporting backward and forward thinking (Chen and Lee, 2003). Other phenomena analyzed in the context of DSS/technology acceptance include illusion of control (Kahai *et al.*, 1998), user resistance (Jiang *et al.*, 2000) and reliance effect (Barr and Sharda, 1997).

Many attempts have been made to explain/predict users' attitude towards technology (Colvin and Goh, 2005; Davis and Venkatesh, 1996; Garrity *et al.*, 2005; Hung and Chang, 2005; Karppinen, 2005; Kukafka *et al.*, 2003; Lee, 2004; Legris *et al.*, 2003; Lim, 2003; Lowry, 2002; McFarland and Hamilton, 2006; Purohit and Kandpal, 2005; Sohn and Ahn, 2003; Straub *et al.*, 1997; Wu *et al.*, 2007; Yang and Yoo, 2004). The Technology Acceptance Model TAM (Davis, 1989), based on the theory of reasoned action TRA (Fishbein and Ajzen, 1975) tried to explained the impacts of external variables on internal beliefs, attitudes and intentions. Two factors were found to determine system use: perceived ease of use (PEOU) and perceived usefulness (PU). External factors act through these beliefs. Subsequently, the TRA and TAM evolved in a number of different models such as Theory of planned behaviour TPB (Ajzen, 1985; Azjen, 1991) and decomposed TPB (Taylor and Todd, 1995). A different approach in behavioural research was taken by diffusion theory (Rogers, 1995), considering technology success as a social process related to the spread and adaptation of innovation, see also (Lee, 2004; Sohn and Ahn, 2003).

7. GUIDELINES FOR THE DEVELOPMENT, IMPLEMENTATION AND APPLICATION OF DSS TOOLS

In this section we translate the outcomes of this study into concrete recommendations for the development, implementation and application of DSS tools. Both the literature review and the survey of DSS tools and end-users opinions were framed within the context of water resources management. Nevertheless we believe that the evidences of this study may be of interest for the broader field of DSS in general.

The development and application of DSS require passing through a series of different choices. We preferred to organize these Guidelines around the idea of a generic temporal sequence, by identifying three main phases:

- Phase A: prior to the actual development or acquisition of the DSS tool;
- Phase B: of development (in case of new tools to be implemented) or acquisition/adaptation of existing ones;
- Phase C: of implementation and application in the decision case.

The sequence is not necessarily universally valid, in particular for what concerns the organisation of the work within the three main phases, because some aspects could be dealt with in parallel, for instance, or be approached at different times in the variety of real world implementations. Subsequent steps with internal iterations are possible, with "control phases" for assessing the quality of the process and its fitting to the application case.

In general, just like a check list, or a collection of recommendations, we believe that professionals and managers involved in cases in which the use of DSS tools is considered, should go through the whole list, in order to, at least, avoid common problems and mistakes that contributed to the –unfortunately very long– list of failures when approaching the development of new tools, or the practical implementations of one of the numerous tools developed in the WRM field over the last 30 years.

It is important to note that the development of a DSS is always a process involving different groups of people, playing different roles. A task force could be identified as that group of few people initiating and managing the process. It usually includes the manager(s) and/or policy/decision makers, the DSS developers, the technical staff at the competent institution, external consultants, experts of different disciplines, e.g. a sociologist for managing participatory approaches, a modeller for integrating simulation capabilities in the DSS package, etc. Other groups may include various categories of actors (stakeholders) involved in various ways and possibly at different stages in the decision process.

7.1 Phase A: before the development or acquisition of a DSS tool

(1) Investigate and describe the problem at hand, the resources available and the data issue

The nature of problems to be solved should be investigated at the beginning of any decision process. In the specific context of examining the adoption of a DSS tool, this should be done with a specific emphasis on clarifying whether or not sufficient human and financial resources could be available. Financial resources could also be needed, for example to consolidate the available data sets. Indeed, the data issue (i.e. the availability of data for informing the decision process) should be approached in order to acquire preliminary information of fundamental importance to choose among the DSS already available or the requirements for a new DSS tool to be developed. Given the complexity of the problems at hand and their specificity to local situations, expert knowledge may provide fundamental support for compensating the lack of quantitative data. In that case adequate techniques are needed for scientifically robust expert elicitation and integration in the decision process.

The outcomes of the survey with DSS users evidenced that quite often a large gap exists between DSS data requirements and data available to users. Moreover human resources (i.e. trained people available within the management administration) are also often limited. When internal human resources are not available, mediators of DSS development and implementation (e.g. external consultants) can play a crucial role at the interface between DSS developers and managers (final users), by providing the administration with the specific skills required and by filling – temporary – gaps of the internal staff.

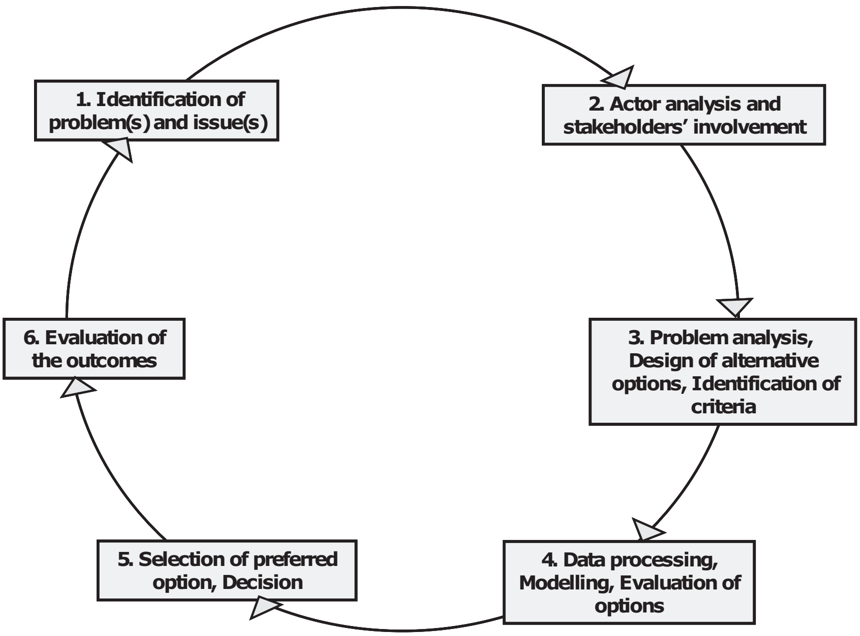

Figure 7.1 A general cycle for the implementation of a decision making process.

(2) Identify the actors involved in the decision and explore the social context

To derive a robust understanding of the problem within its social context the users together with the DSS developer(s) need first to find out whose perspectives/viewpoints are relevant and to apply methods and techniques to make the perspectives explicit. For example:

- identification of relevant actors or categories of actors;
- selection of a representative group of actors without compromising the diversity of knowledge, values and viewpoints associated with the problems;
- exploration of the diversity of views by involved actors.

The HarmoniCop HandBook may provide more details (Ridder *et al*., 2005).

The participatory approach is becoming a prerequisite of every legislation dealing with environmental management. DSS should be developed taking *this need into account: they should be designed to allow multiple users, facilitate the integration of different disciplines and viewpoints, facilitate the transparent processing and inclusion in the DM process of data coming from PP activities.*

(3) Understand the institutional and normative context

The institutional mandate of the user (what decisions users can and have to make, and on the basis of which information), the internal rules and practices within the organisation, and the relation to other institutions should be carefully investigated and clarified.

DSS may impose some degree of change to the decision-making process. It does so with the aim to improve the quality of this process, and subsequently, the decision outcomes. However, any change, be it positive or not, usually encounters a resistance of at least a part of those who are affected, thus increasing the risk of implementation failure. These risks may be reduced by actions targeted to provide timely and effective communication, including the anticipation of possible changes to be expected from the DSS implementation.

DSS impose some degree of change to the end users' practices: some sort of resistance should therefore be expected. Many known failures of DSS tools resulted from the excessive demand of change imposed to the users. Different is the case of changes imposed by new regulations; in that case DSS may be perceived to play a role in alleviating new administrative burdens. The WFD could be an important triggering factor for the adoption of new technologies, such as DSS.

(4) Identify possible constraints

The development of a DSS tool specific for the application in a decision case should adequately consider what the constraints could be to its practical implementation. Two aspects are worth mentioning:

- the technical limitations to the use by the intended users. For instance, in case of web based tools, for participative approaches, requiring efficient Internet connections.
- the limitations coming from the DSS interface and documentation, which should be carefully targeted to the intended users.

DSS interfaces are often developed for experienced users. One common problem is also the language: most DSS are developed in English, but not all the users can understand it.

(5) Raise users' interest and initial commitment

The initial users' commitment requires a clear and comprehensible specification of the system that includes what the system should provide and how. The rising of initial commitment depends upon the extent to which the users perceive the practical utility of the system for the tasks they have to carry out. For the success of DSS the support of a sponsor from within the organisation is most beneficial, preferably among the senior managers, who realise the benefits from the DSS and help to explain it to others.

Frequently quoted indicators for assessing the usefulness are:

- Perceived Usefulness (PU) is one of the central variables in models set to explain success of technology. PU is the degree to which users believe that using a particular system would enhance their job performance.
- Perceived Ease of Use (PEU) refers to beliefs that using a particular system would be free of effort.

Once the decision about the adoption of a DSS tool is taken, efforts should be targeted to raise and maintain the motivation of the whole staff of people involved in the process. This is very important in those cases in which the approach is new and comes from outside the user administration.

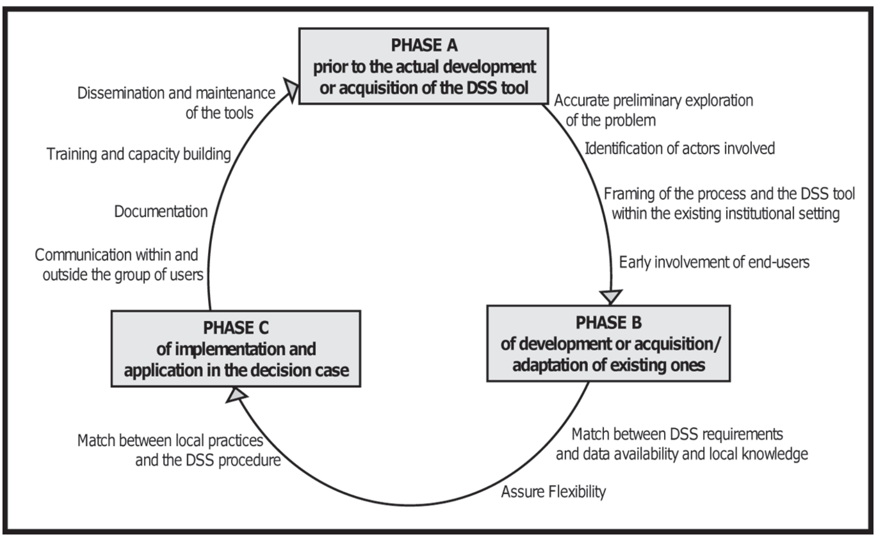

Figure 7.2 The guidelines' flowchart

The perception of ownership of the tool and its implementation by the staff of the user administration is very important for effective application and uptake in normal practices.

(6) Identify and clearly communicate reasonable expectations

DSS can assist the users in a number of ways:

- to surface various perspectives on the problem,
- to reconstruct cause-effect relations,
- to guide the development of policies or predict their outcomes,
- to facilitate collective learning and settlement of disputes,
- to improve social acceptability
- to augment or inform judgements of users and help to avoid systematic biases or inconsistent choices.

The extent to which these contributions to a specific decision process could be provided depends upon many factors, not last the availability of information. A preliminary assessment should make reasonable expectations clear to the end users.

The DSS do not stop users from making judgements, nor should they attempt to do that. Decision makers willing to delegate decisions (and power) to ICT tools are, to say the least, rare.

(7) Decide whether or not a DSS may be useful for the purposes of the case

Phase A should lead the task force to understand clearly whether or not a DSS could be useful for the decision case. Suitable tools are not always necessarily available nor are resources always sufficient to be adapted to the specific case or even for the development of a new tool from scratch (see Box 8 for more insight about this choice).

Box 8: About the decision on whether to apply an existing DSS or whether to develop a DSS from scratch

If an existing DSS has to be applied in a context for which it was not originally developed, then a transfer of knowledge and experiences takes place which may not be an easy task. The transferability is easier if the encountered problems are similar to those for which the DSS was originally developed. Generic interfaces and interoperability increases the technical transferability of DSS.

A number of web portals (such as WISE-RTD or NetSyMod) provide an overview of the available tools and help to choose one of them, according to a number of criteria. The application of existing tools is also favorable (advisable?) because it allows to re-use available tools and to further exploit previous research efforts.

The tools which have been used in practical policy making for some time are more mature, robust and less susceptible to errors or crash. In addition, users can often fall back on substantial experiences collected by others. These experiences, however, are normally not explained and form the users' tacit knowledge.

When applying an existing system, one should carefully verify the DSS' features:

- interoperability: the ability of the DSS to work together with other systems utilized in the users' institution, in order to accomplish a common task;
- data requirements: they impose costs of using the systems, and these costs need to be seen in relation with decisions which are informed by the system. Systems developed in an academic environment are more sophisticated and tend to have higher data requirements;
- methodological background: different tools may yield different results, because they may adopt different methodologies providing "different yet equally legitimate scientific lenses (assumption and theoretical underpinning) for understanding and interpreting nature" (Sarewitz and Pielke, 2000).
- built-in rationality of the tools: this refers to the way decision making is organized. The prevailing approach of current policies is to adopt the public participation (PP) paradigm, but this is not necessarily the approach adopted neither by the tools nor by the current practices of the decision/policy makers.

The development of a new DSS is a better choice in situations when the adaptation of an existing DSS is either too demanding or hardly possible. Moreover, the development process allows better involvement of users in specification and early testing of tools, which has a favorable effect on their commitment to apply the tool once available and trust in the results yielded by the tool. These benefits may under certain circumstances outweigh the higher costs and longer delivery time associated with the development of new systems.

The development of new DSS, while taking advantage of the learning process between users and developers, is facilitated by tools such as modelling

frameworks and DSS generators. These tools allow to design and deploy software 'components' which can be re-used and re-assembled according to users' requirements.
When developing a new DSS remember that:

- DSS are normally built for situations which require complex (social) choices and involve problems which are difficult to grasp in their complexity. In such situations it is difficult to obtain a shared understanding of what the problem is or how it should be tackled. Each problem is specific in its context;
- development of a DSS makes sense in particular when the developers (and the users) expect to face similar problems several times in the near future, or when the development of the system itself helps to take off the edge of the conflict.

7.2 Phase B: the development of the DSS tool, or acquisition adaptation of existing ones

(8) Involve end users throughout the process of the DSS development

Early involvement of the intended users is one of the most critical success factors, but only if both the DSS development and the decision process are ready to adapt to their needs.

As specified later, the development of a new DSS or the adaptation of an existing one is a process of mutual learning between the developers and the users. The users should not be asked to specify their needs only at the beginning of the development, but they should be consulted and involved in the system testing throughout the development process. This has several advantages: the user gains better understanding of the components constituting the system and can consequently better assess the suitability of the system for specific tasks or contexts;

- the user gains early experiences which are valuable for later practical application of the systems.
- the users feel more involved and "powerful" within the process

And disadvantages:

- the time required could constrain the availability of end users
- early involvement includes also a risk of losing critical attitude towards the system which is exemplified in overconfidence with the systems' capabilities or results.

DSS end users are often busy managers: their involvement effort should be carefully managed.

(9) Define a clear strategy and work programme and include quality assurance

There are a number of development strategies or techniques approximating the way systems evolve towards more complex techniques and functionality:

- in the waterfall method development is seen as flowing steadily downwards (like a waterfall) through the phases of requirements analysis, design, implementation, testing (validation), integration, and maintenance;
- a more advanced or flexible process of software development is the incremental and iterative system development, allowing the developer to take advantage of what was being learned during the development of earlier, incremental, deliverable versions of the system. Key steps in the process were to start with a simple implementation of a subset of the software requirements and iteratively enhance the evolving sequence of versions until the full system is implemented. At each iteration, design modifications are made and new functional capabilities are added.
- Prototyping is the process of quickly putting together a working model (a prototype) in order to test various aspects of a design, illustrate ideas or features and gather early user feedback. The availability of an initial system to react to or to improve upon may overcome users' initial difficulties to express what they expect from the system. The prototypes elicit the future expectations of users and provide the system's developers with a continuous flow of user feedback. In this model, only a low level of effort is necessary to rebuild the system after the direction of development has changed.

Quality assurance techniques may significantly contribute towards enhancing the credibility of ICT tools developed at the interfaces between science and policy. The HarmoniQuA web site (http://harmoniqua.wau.nl/) on quality assurance for catchment and river basin modelling can provide practical materials which can be useful also for DSS development in water management.

(10) Adapt tools to the needs and not vice-versa

Building lasting partnerships with the research teams that developed the system makes it easier to adapt the system to changing conditions. This must be an iterative process. Adaptation is easier if one is supported by expert knowledge (e.g. gained through active involvement in the system's development). Quite often pre-existing tools have been proposed to potential end users without an adequate adaptation to the specific needs.

DSS tools should facilitate the work of end users: the effectiveness may increase if they are adapted to build upon the existing data bases and provide outputs specifically designed to meet the formal requirements of the administration.

(11) Refine users' requirements during the development phase

As the development advances, needs, constraints, etc. can be specified in more depth. These specifications include:

- refinements on data requirements and updating available data;
- integration between the tasks fulfilled by the system with other systems used in the institutions;
- new functionalities that may be required;

Since it is often difficult for various reasons to specify the requirements on DSS in depth at the beginning, it is recommended to design the development process with enough flexibility (see next paragraph) to accommodate required reasonable changes. For an example of requirement analysis the reader is referred to the Harmon-IT report (Gregersen *et al*., 2002).

Users' requirements may include the translation of the interface in the local language (see also recommendations 4 & 16).

(12) Assure flexibility

As the DSS development process progresses, the changes to system specification become increasingly costly and require more time. Flexibility can be enhanced e.g. by taking into account up-to-date technical standards for data description (metadata), data exchange (e.g. exchange of spatial data – OPENGIS standards), system description (UML) or component technology. Designing open source systems or providing the systems at no or low costs increases the number of developers and users.

For one of these examples the reader may refer to the Harmoni-IT report on OpenMI (Moore *et al*., 2005).

DSS tools should be adapted to the availability of data (see also recommendation 1), but also to cope with unexpected lack of information. In those cases the ability to implement expert knowledge in the process is of fundamental importance.

(13) Accurately manage and communicate uncertainty

Uncertainty pervades all aspects of environmental policy making. One reason is that policy outcomes are only partly predictable and their associated uncertainties are large enough to sustain persistent conflicts and indecision. Related to this is the tendency for scientists to conceal uncertainty for fear of diminishing their professional credibility and encouraging indecision (Bradshaw and Borchers, 2000). It is also because:

- uncertainty provides a political resource, which can sustain personal beliefs and self-interest (Stirling, 2006; Weiss, 2002).
- Uncertainty poses various philosophical challenges regarding the origin, nature and value of knowledge, ethical challenges regarding acceptable levels of knowledge and risk, its distribution, and who has the mandate to decide, and political challenges regarding how to act when faced with substantial uncertainty.

It also poses several practical challenges, in terms of identifying and describing (quantifying, qualifying) uncertainties, propagating them through decisions and communicating the results of an uncertainty analysis.

The guidance report on uncertainty analysis can provide practical materials for further reading (Refsgaard *et al.*, 2010)

The adoption of the DSS should encourage the competent administration to deal with the various sources of uncertainty and include their treatment in the communication of results.

7.3 Phase C: DSS implementation and application in the decision case

(14) Provide a coherent methodological framework in which the DSS tool should operate

The tools per se do not guarantee the quality of the process. DSS should be framed within methodological frameworks in which all the phases and components of the policy/decision making process are considered.

The recent research projects, in particular those supported within the EU Research Frameworks have delivered a variety of methodological proposals in this field.

Various attempts have been made with the aim of facilitating the dissemination of tools (see for instance the WISE-RTD portal at http://www.wise-rtd.info/) but also of the methodological frameworks: the NetSyMoD portal is an example (http://www.netsymod.eu/), and the Guidance for Integrated Deliberative

Decision Processes developed by the Project Advisor (http://ecoman.dcea.fct.unl.pt/projects/advisor/iddp/).

(15) Provide effective documentation of the limitations of the results provided

DSS, like simulation models, encode knowledge, but they do so selectively, leaving out what is not perceived as relevant and what cannot be formalised. Preserving the relevant features, while discarding the unnecessary complexity can be the main strength of models and DSS, but it should be carefully managed. The choice of what is relevant and how this choice is made is crucial.

The communication of the process and its outcomes is always a very challenging issue in which the subjectivity and bias of the users and developers may play a relevant role.

The quality of the DSS results is determined by the quality of the decision processes and the usefulness of the outcomes depends on the quality of the communication (and training) strategy.

The results of DSS applications should be adequately documented, and assumptions, subjective choices and uncertainties of various kinds should be transparently communicated with charts, tables, and statistical annexes. Such documentation should allow interested people to go deeper step-by-step in the understanding of all the details of the decision process.

(16) Provide adequate documentation and support materials all together with the DSS tool

The final delivery package should include a handbook, methodological guide, tutorial and other additional features to increase the prospects of the system and reduce unintended misuse of the system. The inclusion of application examples can be very helpful in this regard. It is also recommended to provide the opportunities for collecting feedback and assessing the satisfaction with the tool.

An online discussion forum where the users can post their questions and report about problems/issues they experienced can be a valuable support for both the developers and users (several examples could be mentioned in particular in cases of fora/lists connecting the user's communities, for example in the case of RiverWare).

(17) Train users

Through training, the familiarity with the system increases as does the perceived usefulness of the system. Training should not be restricted to explaining how to use the software, explanations of the theoretical background and methodological strengths and weaknesses are vital for correct usage of the system. Clarifications of what the DSS cannot provide can also be helpful.

Training of users may become a crucial aspect to allow the reuse of tools outside and after the initial development environment.

(18) Exploit the full potential of the tool in supporting the whole process

The most valuable result of a DSS is the understanding of the problem at hand in its complexity. Even if the DSS yields practical recommendations such as ranking of various policies, these should not be adopted uncritically.

The success of the DSS implementation and application does not depend only upon the adoption of the results. The improvement of the quality of the decision process is the main indicator of success

Even the case of a DSS becoming obsolete because the end user has learned (by using) its logic and is able to apply it on his own (without the tool), could be considered a successful case.

(19) Provide the basis for maintenance and further development

A DSS is hardly ever finished. In order to remain useful, it has to be continuously updated. Maintenance means the commitment of the developer to assist users beyond the development project and after the final version of DSS has been released. This requirement can hardly be satisfied with the usual structure of research grants which are limited in time to 3-4 years and do not provide specific opportunities for follow up activities, such as the maintenance and dissemination of the products, training activities, etc.

Many DSS developed in an academic environment lack long-term commitment and consequently, their usability decreases in time. Development of lasting partnerships is beneficial for both developers and users.

Various strategies are possible, at the EU level, in order to provide opportunities for longer time development and maintenance:

- include requirements for dissemination and exploitation activities within the call for proposals of research projects in this field;

- facilitate transfer of knowledge to non-academic institutions – involved in project consortia – that may be interested in commercial exploitations;
- provide specific forms of financial support for facilitating the adoption of selected tools, or
- identify lists of operational tools to be used for coping with the various requirements of directives and regulations.

(20) Adopt strategies for dissemination and technology transfer

It is clear that the current system of research grants is not designed for supporting the transfer of technology from the academic environment to the policy sphere. The end of the research grant often coincides with the release of the prototype. A follow-up phase would be necessary for implementing actions targeted to the release of the operational tool and its dissemination to potential users.

DSS end users identified the need for proposals for technology transfer and for supporting the development from the prototypes to the operational tools. Moreover specific dissemination efforts are required (e.g. "a travelling team of DSS experts who can visit staff on the field and work out case-studies together.

Box 9: Comments to the Guidelines from the user perspective (Marco Tamaro)

Phase A

One of the main limitations towards the widespread application of DSS lies on the inadequate manager's perception of the role of these tools in supporting the decision making process. In fact, DSS aim more at providing complementary rather then substitutive functions.

The contributions of experts who are adequately trained for modelling of complex scenarios is fundamental. Similarly the tools which are meant to be applied by the users themselves need to be simply tailored to support specific tasks in the decision process. Point 1 in the guidelines ("Investigate and describe the problem at hand, the resources available and the data issue") is the most difficult to put in practice. All DSS should consist of suitable methodologies to allow the implementation of the process in a participatory way. It is fundamental that the process remain flexible enough to allow the adoption of the tool in more than one decision context. The use of the system for the evaluation, documentation or validation of previously adopted policies should not be considered improper, even if the full potential of the tool is not fully exploited. This type of application fosters the feedback on already implemented policies and it offers a training opportunity, useful for future applications. The test of previously taken decisions could encourage the decision maker to overcome misconceptions towards DSS. The tool needs to be adapted to the management and not vice versa. It is important to keep the data requirements as low as possible. The quality of the system's results depends more on the choice of parameters and weights, followed by a sensitivity analysis, than on the degree of the system's sophistication. Points 6 and 7 in the guidelines are very important and depend on the capacity of the consultant to communicate the usefulness and potential of the tool.

Phase B

The developer has to be part of the project's team and has to collaborate with the manager to develop a system suited to his needs. At this point brainstorming techniques, if effectively used, can reduce the time generally requested for the system's implementation. Flexibility and efficiency (i.e. it is not necessary to spend resources for the automatic import of data) are central for the system development. It is advisable to use and to import data (with cut-and-paste) from external standard applications which are used as pre-processing tools.
Uncertainty should be appreciated, in that it is naturally part of the decision-making process.

Phase C

The application of the methodology has to be coherent with the previous development phases, of course if it's not aiming at the evaluation of a decision that has been already taken.
If trained users or experts are not available in the end users' institution, the direct and autonomous use of the tool should be confined to the final phase, in which the weights and value judgements are surfaced. The tool should assist the end user by assessing the coherence of the judgements. This final phase permits the manager to gain control and prevents failures due to the managers' perception of being restricted in their decision functions. For this reason it is necessary to critically review the results (i.e. what would have happened if parameter X had been judged as more important with respect to Y or Z?).
It is the role of the developer/adviser to assure an efficient and periodical contact with the end user to elicit feedback and adapt the tool to the end users' needs.

8. OUTLOOK

This work contains many suggestions and practical advice that can be useful for future DSS developments, but it clearly does not provide a detailed recipe for success. Although many ingredients of such a recipe are known (e.g. early end-users' involvement or system flexibility), their exact dosage (quantity and quality) is to a large extent context-dependent. What has worked out in one context is no definite guarantee for success in a different context.

Nevertheless, we believe that the present work may contribute to fill a specific gap of knowledge on recent experiences in DSS developments and applications in the water management field, leading to the definition of a set of guidelines that can be considered valid in general, and helping to avoid past mistakes, knowing very well that they should be significantly tailored and adapted case by case. Therefore, the recommendations reported in Section 7 should be considered a checklist or a to-bear-in-mind caution which is appropriate for any effort to employ formal models and computerized tools in the context of policy/decision-making processes.

We should always remember that policy and decision makers are already solving their relevant decision problems. Analyzing how the decision process is currently carried out is always a prerequisite for DSS development. When the current practices are unstructured and/or non-transparent, the DSS potential increases, given that there is sufficient willingness to change. Moreover, it is known that different decision makers may lead to different conclusions for the same case. Similarly it should be expected that different results can come from the use of alternative models and DSS tools, but also from the use of the same tools by different users.

This document has benefited from the revisions of numerous colleagues in Europe and elsewhere. During the revision process many suggestions have been collected. Most of them have been implemented as far as possible in this final version, others went well beyond the limits the work and they contributed to the list of activities to be left to future – research – work that we present below.

- The various benefits of DSS, the real needs of DSS end-users and the ways in which DSS can meet these needs could be investigated in greater detail. Moreover, what benefits DSS will actually bring in terms of organization (i.e. effectiveness and efficiency improvements, learning processes), and in terms of environmental standards, or whether there is any evidence that DSS will actually produce such benefits could be further assessed. It might be useful to mention specific examples of how DSS (both within and without the context of the WFD) could help to structure complex water management problems.

- Related to the previous point is the question of knowledge demand and knowledge supply (i.e. what do policy and management organizations need in terms of know-how, know-what, know-why, etc.). This issue could be tackled by exploring the way in which knowledge demands can be delivered through DSS development and DSS application. In this regard the relevant questions are: what knowledge do river basin management organizations want or need and how do they want to access it? And what are DSS developers offering? The answer to these questions will contribute to a more accurate definition of the knowledge gaps in water policy and management.
- The report does not deal specifically with the methods needed to actually apply scientific results in decision making situations using DSS as a knowledge transfer tool, when mediators, such as private consultants, play an important role. More efforts are needed in that direction.
- Proposals for technology transfer of DSS from the research prototype to the operational tool can be further investigated. In this regard, it would be useful to tackle the subject of water policy and management organization's knowledge acquisition and management practices by ad hoc efforts.
- More should be done to analyze the potential role of academia in relation to the innovation of current management systems and the observed reluctance to use DSS. For this purpose a comparison of different systems, for example between the systems developed in-house with those developed by research projects, could be helpful. Long-term analysis of the development of tools through interactions with practitioners could also provide useful insights.
- The role of market as compared to free distribution of research products could be explored to identify more effective transfer and dissemination strategies.
- Opinions of different DSS users' groups to stress the different perspectives of users and developers could also be done by referring to the geographic distribution of DSS development and applications.

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10. APPENDICES

10.1. Appendix 1: Comprehensive list of DSS tools examined

	Tools	Developed by	Project
1	WSM DSS	National Technical University of Athens, Greece; Ruhr-University, Germany; ProGEA S.r.l., Italy	WaterStrategyMan (EU)
2	WATERWARE	Environmental Software and Services (ESS), Austria	Integrates results of the EUREKA project EU487 and related projects
3	ELBE-DSS	Research Institute for Knowledge Systems (RIKS), Maastricht NL; Dept. of Water Engineering & Management, University of Twente NL; Inst. f. Umweltsystemforschung, Univ. Osnabrück; Infram, Marknesse NL, Federal Institute of Hydrology (BfG)	Elbe-DSS
4	MDSS	Fondazione Eni Enrico Mattei (FEEM), Italy	MULINO (EU)

Appendix 1 *Continued*

5	MONERIS	Department of Shallow Lakes and Lowland Rivers; Leibniz-Institute of Freshwater Ecology and Inland Fisheries part of the Forschungsverbund Berlin e.V., Germany	
6	MERIT-DSS	The partners of the MERIT project (The guidelines for participatory use of BNs for integrated water resource management (see www.merit-eu.net). The code developer is the Machine Intelligence Group at Aalborg University, Denmark	MERIT (EU)
7	RIVERWARE	Centre for Advanced Decision Support for Water and Environmental Systems, University of Colorado, USA	
8	DELFT-TOOLS	Delft Hydraulics, The Netherlands	
9	CATCHMODS	Integrated Catchment assessment and management centre (iCAM), Canberra, Australia	
10	RAMCO	National Institute for Coastal and Marine Management and the Research Institute for Knowledge Systems (RIKS), The Netherlands	LWI-project
11	MODULUS	Research Institute for Knowledge Systems (RIKS), Maastricht, The Netherlands in collaboration with the MODULUS Consortium	MODULUS (EU)
12	MEDACTION	Department of Civil Engineering, University of Newcastle Upon Tyne, United Kingdom; Research Institute for Knowledge Systems (RIKS)	MedAction (EU)
13	ECOVISIE	Research Institute for Nature and Forest (INBO), a scientific institute of the Flemish Government in Belgium; Ministry of the Flemish Community (AMINAL), Department of Nature Brussels, Belgium; Research Institute for Knowledge Systems (RIKS)	EcoVisie

Appendix 1 *Continued*

14	DADSS	Finnish Environment Institute (SYKE), Finland	VHIMA
15	DANUBIA	Department of Earth and Environmental Sciences Chair for Geography and Geographical Remote Sensing, University of Munich, Germany	GLOWA-Danube
16	TIDDD & DTS	Gesellschaft fur angewandte Informatik mbh (FUTURE-tec Gmbh) in collaboration with Centre d'Economie et d'Ethique pour l'Environnement et le Développement (C3ED) Université de Versailles, France; the European Commission - Joint research Centre, Institute for the Protection and Security of the Citizen.	GOUVERNe (EU)
17	MIKE	Danish Hydraulic Institute (DHI), Danemark	
18	BAYES NET	Duke University, Durham, NC, USA	Neuse River, Estuary Modeling and Monitoring (ModMon)
19	GREAT-ER	Procter & Gamble ETC, Belgium; ECETOC, Brussels, Belgium	
20	AQUATOOL	Institute for Water and Environmental Engineering (IIAMA), Universidad Politecnica de Valencia, Spain	
21	HDSS (Hula Decision Support Sysrtem)	Faculty of Civil Engineering, Technion-Israel Institute of Technology, Israel	Hula Project
22	TRANSCAT-DSS	Instituto de Soldadura e Qualidade, Portugal (Project coordinator)	TRANSCAT (EU)
23	WMSS (Water Management Support System)	(Bureau de recherches géologiques et minières) BRGM, France	MEDITATE (EU)
24	WFD-EXPLORER	Delft Hydraulics, The Netherlands	
25	MOIRA DSS	ENEA Divisione Protezione dell'Uomo e degli Ecosistemi Centro Ricerche Casaccia Roma, Italy	MOIRA (EU)

Appendix 1 *Continued*

26	EIADSS (The Evaluation/Prediction of Environmental Impact Assessment for Irrigation Project)	Center for Environment and Development for the Arab Region and Europe (CEDARE), Cairo, Egypt	
27	REAL-LIFE Scale Integrated Catchment Models for Supporting Water- And Environmental Management Decisions	Water Resources Research Centre (VITUKI), Hungary	The Tisza River (EU)
28	DECIS Decision Making / Management	Consorzio Venezia Ricerche (CVR), Venice, Italy	MODELKEY (EU)
29	TWOLE	Sistemi Ambientali e Territoriali (SAT) group at Politecnico di Milano, Dipartimento di Elettronica e Informazione (DEI), Italy	TwoLe (EU)
30	DSS for the Assessment of Flood Risk	HR Wallingford Ltd, Wallingford UK (Co-ordinator)	EUROTAS (EU)
31	STREAMPLAN	International Institute for Applied Systems Analysis (IIASA)	
32	DESERT	International Institute for Applied Systems Analysis (IIASA)	
33	DSS-DROUGHT	University of Catania, Institute of Hydraulics, Hydrology and Water Resource Management (project coordinator)	DSS-DROUGHT (EU)
34	DSS for fte Management of Integrated Water Resources Systems Focused to Drought Prevention and Mitigation	University of Catania, Catania, Italy (project coordinator)	WAM-ME (EU)
35	DSS for Sustainable Ecosystem Management in Atlantic Rain Forest Rural Areas	Universidade Atlântica and Universität Hamburg (project coordinators)	ECOMAN
36	RAMFLOOD-DSS (for Risk Assessment and Management of Floods)	Centre Internacional De Metodes Numerics en l'Enginyeria (CIMNE) Barcelona, Spain (project coordinator)	RAMFLOOD (EU)
37	INFRAPLAN	Cranfield University, United Kingdom	TiGrESS

Appendix 1 *Continued*

38	SCAPT (Strategyc Catchment Analysis Planning Tool)	Cranfield University, United Kingdom	AQUADAPT
39	Decision Support System for the Effective Management of Freshwaters	ULIV - University of Liverpool, United Kingdom	EURO-Limpacs
40	DSS FOR URBAN SYSTEM ASSESSMENT	AGK - Applied Geology Karlsruhe, University of Karlsruhe, Germany	AISUWRS (EU project)
41	ADSS (Adaptive Decision Support System)	CEREVE, Centre d'Enseignement et de Recherche sur l'Eau, la Ville et l'Environnement; Common research centre UPVM, ENPC, ENGREF Ecole Nationale des Ponts et Chaussées (ENPC), France	DayWater (EU)
42	Decision Support Tools for Sustainable Water Network Management	CARE-W consortium	CARE-W (EU)
43	DSS for Rehabilitation of Sewer Networks	CARE-S consortium	CARE-S (EU)
44	DSS for Flood Prevention And Protection	Council for The Central Laboratory of The Research Councils, Department of Information Technology, Rutherford Appleton Laboratory, United Kingdom	ANFAS (EU)
45	GIBSI (Gestion Intégrée des Bassins Versants à l'aide D'un Système Informatisé)	Institut national de la recherche scientifique (INRS), Centre Eau, Terre & Environnement, Québec, Canada	
46	NELUP-DSS	University of Newcastle. Dep. Of Civil Engineering,	NERC-ESRC Land Use Programme (NELUP)
47	RAISON	NWRI Software National Water Research Institute, Canada Centre for Inland Waters, Burlington, Ontario, Canada	
48	FLOODWORKS	Wallingford Software Ltd, Oxfordshire, United Kingdom	

Appendix 1 *Continued*

49	WAMADSS (Watershed Management Decision Support System)	Centre for Agricultural, Resources and Environmental systems (CARES) University of Missouri, Columbia, USA	
50	WATERSHEDSS (Water, Soil, And Hydro-Environmental Decision Support System)	NCSU Water Quality Group at North Carolina State Universityand the Agricultural and Biological Engineering Department at The Pennsylvania State University, USA	
51	ILRDSS (Illinois River Decision Support System)	Illinois State Water Survey; Illinois Natural History Survey; Illinois State Geologic Survey, and Waste Management and Research Centre; Illinois Department of Natural Resources, USA	
52	MODSIM-DSS	Colorado State University, Civil Engineering Department, USA	
53	FLOODRELIEF-DSS	Danish Hydraulic Institute (DHI) Water & Environment, Denmark	FLOODRELIEF (EU)
54	REALM (RESOURCE ALLOCATION MODEL)	Department of Sustainability and Environment, Victoria, Australia	
55	BASINS (BETTER ASSESSMENT SCIENCE INTEGRATING POINT AND NONPOINT SOURCES)	US Environmental Protection Agency (EPA), USA	
56	IQQM (INTEGRATED QUANTITY AND QUALITY MODEL)	Department of Infrastructure, Planning and Natural Resources (DIPNR), Australia	
57	WEAP (WATER EVALUATION AND PLANNING SYSTEM)	The Stockholm Environment Institute, Hydrologic Engineering Center of the US Army Corps of Engineers funded significant enhancements.	
58	OASIS (STAKEHOLDER TOOL FOR WATER RESOURCES)	HydroLogics, Inc., USA	
59	DELFT-FEWS (FLOOD EARLY WARNING SYSTEM)	Delft Hydraulics, The Netherlands	
60	MADWICA DSS	Aquatest S.A., Geologická, Czech Republic	EUREKA E! 2721 MADWICA (EU)

10.2. Appendix 2: Presentation of short-listed DSS tools

10.2.1. CatchMODS

Primary scope/domain: The Catchment-scale Management Of Diffuse Sources (CatchMODS) model aims to assist users to identify appropriate forms of management intervention to reduce nutrient inputs to the Ben Chifley Dam Catchment (BCDC). CatchMODS also provides a vehicle for communication and interaction with managers and the catchment community.

Technical design: CatchMODS is a scenario-based modelling tool. Several of the processes represented in the SedNet model are integrated (Prosser *et al.*, 2001) and the IHACRES model (Jakeman *et al.*, 1990) is used to estimate surface and sub-surface discharge in the modelling network. CatchMODS includes two nutrients submodels that simulate total nitrogen (TN) and total phosphorus (TP) export and an in-reservoir plankton-response model (specific to the Ban Chifley Dam catchment). A number of socio-economic factors are considered in the model, mostly the costs associated with the available preventative and remediation options.

The model operates with two modelling platforms. Spatial data pre-processing is undertaken using GIS-based queries for each subcatchment and river reach. The other modelling platform used is the Interactive Component Modelling System (ICMS). ICMS is used to perform the modelling and deliver an integrated Decision Support System. ICMS is an object-oriented modelling environment incorporating various models and data used in catchment management modelling. CatchMODS is based on a series of linked river reaches and associated subcatchment areas. A user interface has been developed for the BCDC application of CatchMODS and can be readily modified for new model applications.

Support provided: CatchMODS is designed to support stakeholders focus remediation on specific subcatchments and encourage sustainable management practices more broadly in the catchment. It enables development and testing of realistic land management change scenarios, and has provided valuable information on likely adoption rates for recommended management practices.

Distribution and maintenance: CatchMODS and the associated ICMS software are freely available under licence. To encourage appropriate use of the DSS its distribution is limited to those who have participated in specific CatchMODS training workshops. In the interests of transparency, the underlying code of the DSS can be accessed by all model users but modification is discouraged. Further development of CatchMODS DSS is in progress with the objective of expanding the capabilities of the modelling and increasing confidence in model outputs.

Users and applications: CatchMODS has been used to identify subcatchments that have high pollutant source and transport strengths relative to the remainder of the BCDC. Prototypes of the model have also been developed for several other catchments including the Moruya River and Colia Lake catchments, NSW and the Cox Creek catchment, SA.

Documentation: CatchMODS is distributed with a user guide including a description of the underlying model and tutorials on how to construct scenarios and examine results.

Main scientific papers:

Newham, L.T.H., A.J. Jakeman and R.A. Letcher (submitted) End-user participation in modelling for integrated catchment assessment and management: An Australian case study in participation. *International Journal of River Basin Management*;

Newham, L.T.H., A.J. Jakeman and R.A. Letcher (2006) Stakeholder participation in modelling for integrated catchment assessment and management: An Australian case study. *International Journal of River Basin Management.* **4**(3), 1–13.

Newham, L.T.H., R.A. Letcher, A.J. Jakeman, T. Kobayashi (2004) A framework for integrated hydrologic, sediment and nutrient export modelling for catchment-scale management. *Environmental Modelling & Software*, **19**, 1029–1038;

Development: The Ben Chifley Dam catchment study was assisted by the NSW Government through a grant from their Environmental Trust. The Department of Environment and Conservation (DEC) a NSW Government agency established a water quality monitoring program to support the development of the CatchMODS model. The development of CatchMODS was supported by close user participation during the case study.

10.2.2. Elbe-DSS (Pilot-Version)

Primary scope/domain: The tool's main purpose is the implementation of an IRBM tool in the German part of the Elbe river basin. The system addresses water quantity, chemical quality, highwater and navigation related aspects and ecological status of waters and the floodplain. The interaction of management objectives, external scenarios of climate, agro-economic and demographic change, and selected measures to achieve the desired state of good water quantity and quality, flooding safety and the ecological status of floodplains is investigated.

Technical design: The Elbe-DSS contains a user-oriented interface (in German), which allows handling of models and access to GIS-based information. A first, partly translated version in English is integrated. A modular, scale-related system diagram was drawn up that includes the modules "catchment", "river network", "main channel" (river plus flood-plain), and a 10-km "river section" including the floodplain) in the present version. These modules work in different spatial and temporal resolutions. The users of the DSS may select and enter planned "measures" by which they want to achieve their "management objectives". The previously defined "indicators" describe the degree of attainment of an objective. With these indicators, the user can have the consequences of his/her activity policy displayed and assessed. Additionally, the user may select previously computed "external scenarios", such as climate-change or land-use scenarios. Evaluation tools have been provided for various kinds of decision-making, e.g. risk-based for hazardous pollutant concentrations, monetary-based for engineering measures or ecological services for floodplain restoration. Different models are integrated, for example a model for the calculation of the long-term nutrient discharges from non-point sources (MONERIS) and a simulation model for wastewater pathways (point sources) and aquatic fate assessment (GREAT-ER). Further different models for hydrological dynamics were integrated. To set up all tools and models within one system the DSS-generator software GEONAMICA, developed by RIKS, and additional software was used. The Elbe-DSS is a PC application for Windows NT, 2000, XP. Under Windows NT at least 256, better 512 MB, are recommendable; under Windows XP at least 512, better 1 GB. Microsoft Excel (>2000) and Internet Explorer need to be installed at the users' PC.

The Elbe-DSS is available in a pilot-version. It will be further developed in future.

Support provided: The DSS has the purpose to facilitate the assessment of the impacts of management options. It highlights cause-effect relations and the sensitivity of different actions. To this end the DSS structures complex problems. Sectoral knowledge and available models are pooled within a basic framework. By applying a customised user interface they are made applicable in the management context. It supports the evaluation of the policy impact and scenario development. It is also intended to support participative decision making.

Distribution and maintenance: The Elbe-DSS is freely downloadable at http://elise.bafg.de/?3283. The pilot-DSS offers an operable system with an interface that is tailored to the specific requirements of users. It will be appropriate to speak of a genuine DSS for real-life decision-making when up-to-date data of the users are provided and functionalities are finally adapted. This implementation process is ongoing.

Users and applications: Potential end-users of the DSS include Internationale Kommission zum Schutz der Elbe (IKSE), Arbeitsgemeinschaft zur Reinhaltung der Elbe (ARGE-Elbe), Ministries of the "Länder" in the catchment area, Biosphere Reservations, Water management associations and authorities, Federal Waterways and Shipping Directorates (WSV), Federal Institute of Hydrology (BfG), Federal Waterways Engineering and Research Institute (BAW), Federal Ministries of Agriculture and Environment (BML, BMU), Federal Environmental Agency (UBA).

Documentation: A context-sensitive library function is generated by means of an on-line help format (WinHelp, HTMLHelp). It is structured through hypertext and internet links and allows rapid access to the desired information. For all integrated models, the scientific approaches are described, and instructions how to handle the DSS features are given. Additionally a number of documents describing different phases of the development are available on the Elbe-Informations-SystEm (ELISE) web site (http://elise.bafg.de/?3283).

Main scientific papers:

Kok, J.L. de and Kofalk S. (2006) Towards a user-oriented design of DSS for integrated river-basin management: the Elbe DSS prototype, 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. CD ROM. Internet: http://www.iemss.org/iemss2006/sessions/all.html.

Matthies, M., Berlekamp, J., Lautenbach, S., Graf, N. and Reimer, S. (2006) System analysis of water quality management for the Elbe river basin. *Environmental Modelling & Software*, **21**(9), 1309-1318.

Berlekamp, J., Lautenbach, S., Graf, N., Reimer, S. and Matthies, M. (2005) Integration of MONERIS and GREAT-ER in the decision support system for the German Elbe river basin. *Environmental Modelling & Software*, In Press, Corrected Proof;

Kok, J.L. de and Huang, Y. (2005) Assessment of flood risk at various scales - The Elbe prototype DSS. In: Van Alphen, Van Beek, and Taal (Eds.), *Floods, from Defence to Management, Symposium Papers of the 3rd International Symposium on Flood Defence*, Nijmegen, The Netherlands, 25-27 May 2005, Taylor & Francis Group, London.

Development: The Federal Institute of Hydrology (BfG) initiated the design and development of the Elbe-DSS. The consortium was comprised of Bundesanstalt für Gewässerkunde, INFRAM, RIKS, Universität Osnabrück, Universität Twente. A feasibility study was completed, before the development process started. User needs were identified and refined by repeated consultation of water managers. A list of management objectives, measures, and external scenarios emerged, which was taken as the basis for the DSS development.

10.2.3. KerDST

Primary scope/domain: The KerDST (Deliberation Support Tool) is designed to function as a complement to scenario modelling and spatial (e.g. GIS based) representations and integrates the KerBabel Deliberation Matrix with its associated KerBabel Indicator Kiosk (KIK). The Deliberation Matrix permits a comparative multi-criteria multi stakeholder evaluation of scenarios for regional futures or for farm practices, and the KerBabel Indicator Kiosk helps make feasible an accessible and comprehensive documentation of information sets used in modelling and maps. The Deliberation Matrix presents, in a synthetic way, the array of judgements offered by stakeholders concerning alternative perspectives on management of the environmental resource. KerDST is applied in projects that deal with agriculture activities and choices at different spatial scales (farm scale, district or sub-catchment, and finally regional scale) and also contrasting timescales (long term planning or on-going monitoring).

Technical design: In the Deliberation Matrix, the scenarios of distinct possible futures are evaluated from distinct stakeholder perspectives. A small number of major stakeholder categories are specified, based on institutional and interview analyses. The procedure of evaluation allows for the existence of diversity within each major stakeholder category. The stakeholders' may make their evaluations of each scenario in terms of a variety of different criteria The criteria are grouped into a small number of 'baskets' corresponding to distinct governance issues. The KIK is, in itself, a generic deliberation support tool whose meta-information structure addresses the contexts of indicator use and pertinence as well as the more traditional domains of information sources. The Deliberation Matrix and the KIK are seen as naturally coupled, and the KerDST system establishes this coupling for use on-line. System' requirements: Firefox browser Macromedia Flash Player 7 and up.

Support provided: The KerBabel Deliberation Matrix provides the framework for a qualitative multi-stakeholders multi-criteria comparison of scenarios (or sites or options, etc.) by a single person or a community of users. The integrated KerDST Deliberation Matrix with associated Kiosk (KIK) allows multi-criteria evaluation to be supported by indicators and, in the "participatory option" allows judgements by each category of stakeholders to be produced as a composite outcome of multiple participants. Ideally, these tools help to develop and then maintain involvement of members of the business and wider communities around the planning or business choice questions (such as taking environmental quality into account in farming).

Distribution and maintenance: The KerDST is an on-line tool, developed with 'Open Source' conventions. Since 2006, the KerBabel Deliberation Matrix has been made available (http://kerdst.c3ed.uvsq.fr/). The integrated KerDST system of the Deliberation Matrix with associated Kiosk (KIK), is available on http://iacaprod.c3ed.uvsq.fr/kerdst2/.

Users and applications: The prototype kerDST system is in use in the SRDTOOLS EU project during 2005, and saw its prospects for the stakeholder based regional futures studies and sustainable agriculture evaluation work that AgResearch, New Zealand (www.agresearch.cri.nz/) is engaged in. The use of kerDST is now incorporated in several projects including “Choosing Regional Futures” (led by the Environment Waikato, the regional council concerned), and a set of industry sponsored projects intended to define methods for incorporating environmental and social performance considerations into assessment of agriculture strategies at farm, district and regional scales, e.g., river water quality and chemical runoff from intensive dairy farming.

Documentation: The system is distributed with a manual: “How to do it. A user’s Manual for KerDST Deliberation Matrix. Non Participative KerDST using the Indicator Dialog Box.” prepared by Martin O’ Connor (Université de Versailles-St Quentin en yvelines - UVSQ), Victoria Reichel and Pierre Bureau (C3ED). Detailed documentation of KerDST system can be found in a series of internal C3ED documents C3ED (e.g., Bureau, Legrand, O’Connor & Reichel, 2007).

Development: During the GOUVERNe (“Guidelines for the Organisation, Use and Validation of Information Systems for Evaluating Aquifer Resources and Needs-Funded by DG RTD, 5th Framework Programme” - Contract. No. EVK1-1999-00032) and then VIRTUALIS (“Social Learning on EnVIRonmental Issues with the InTeractive Information and CommUnicAtion TechnoLogIeS” - Funded by the EC, 5th Framework Programme, 2001-2004 -Contract IST-2000-28121), the C3ED (Centre d’Economie et d’Ethique pour l’Environnement et le Développement) and partners have developed and experimented with various aspects of on-line “deliberation support tools”. KerDST has been developed and tested in the context of the SRDTOOLS project (“Methods and Tools for evaluating the Impact of cohesion policies on Sustainable Regional Development”, Funded by the EC 6th Framework Programme, 2005-2006, Contract No.502485).

10.2.4. MERIT DSS

Primary scope/domain: MERIT DSS is a generic integrated management tool based on the concept of Bayesian belief networks (BBNs) developed to provide an integrated and participatory water resource management methodology suitable for use throughout Europe at river basin scale. This practical and effective methodology and guidelines for construction of BBNs with stakeholder involvement enables managers to make multi-objective decisions, ensuring that stakeholders are engaged in the participatory decision-making process.

Technical design: The approach essentially consists of a decision support tool based on probability theory and Bayesian belief networks (BBNs), with guidelines for the use of BBNs as a participatory tool for Water Resource Management (Bromley, 2005). BBNs are policy development and dialogue tools able to represent the environmental system as a network of nodes linked so as to represent cause and effect within the system. Each node represents a variable and can be of any type (environmental, social, economic, etc.), and the “cause and effect” links between them can be simulated using a range of analytical techniques based on whatever data are available. The impact of a decision can be evaluated by entering the action into the relevant node (variable). This change will then have a knock on effect on all those nodes linked to it, thus the impact on the entire system can be evaluated. Results are presented as bar graphs showing the state of each variable in terms of probability distributions, thus explicitly representing the degree of uncertainty in the system. The explicit recognition of uncertainty helps decision-makers to identify more clearly the risks associated with different management strategies. A Bayesian network package called HUGIN (www.hugin.com) was used to develop the networks. The results were obtained using a procedure known as propagation. The HUGIN decision engine (HDE) performs reasoning on a knowledge base represented as a Bayesian network or an influence diagram. The HDE performs all data processing and storage maintenance associated with the reasoning process and allows application program interface or C, C++, and Java, and an Active X server. The language used in the guidelines and the documentation of the HUGIN interface is in English, but it is possible to construct the BNs using any language for the names of variables, states and documentations within the BBNs, so that the participatory use can be in any selected language.

Support provided: There is no single appropriate method of engagement replicable in all circumstances. Only the principles of engagement are replicable. Strength of BBNs are:

- BBNs are very visual; it is easy to demonstrate the way in which a system functions through the use of variables and links
- Can be used to integrate environmental, economic, social, cultural and political variables
- Permits impact of many different strategies and / or scenarios to be assessed in a short time
- Provides an excellent focus for dialogue with stakeholders
- Decisions made with a BBN are transparent when used in conjunction with stakeholder groups

Distribution and maintenance: The MERIT guidelines for the use of BBNs as a participatory tool for Water Resource Management are freely available including a free HUGIN viewer for the four case studies from MERIT. HUGIN is commercial software and maintained and used for a variety of different purposes (see www.hugin.com). The MERIT guidelines and the use of HUGIN as a participatory tool is further enhanced as a fast track existing tool in the EU research project NEWATER (2005-2008).

Users and applications: The approach was applied during the project implementation in the context of four case studies: the Havelse wellfield catchment in North Zealand (Denmark) for wich Geological Survey of Denmark and Greenland (GEUS) was the project leader and Copenhagen Energy (CE) the decision-maker and end-user in relation to the BBN case study; by the Junta Central de Regantes de La Mancha Oriental (Spain) for the Jucar catchment, by the Sperimentale Italiano Giacinto Motta S.p.a - CESI (Italy) for the Vomano catchment and by Centre for Ecology and Hydrology – CEH (UK) for the Loddon catchment. The system has been used beyond the MERIT project e.g. in Denmark for the purpose of integrating hydrological and economic models.

Documentation:

Main scientific papers:

Henriksen, H. J., Rasmussen, P., Brandt, G., Bülow, D. von and Jensen, F. V. (2007) Bayesian networks as a participatory modelling tool for groundwater protection.

Henriksen, H. J., Rasmussen, P., Brandt, G., Bülow, D. von and Jensen, F. V. (in prep.) Public participation modelling using Bayesian networks in management of groundwater contamination. *Environmental Modelling & Software.* In Press, Corrected Proof, Available online 3 April 2006.

Bromley, J. (2005). Guidelines for the use of Bayesian networks as a participatory tool for water resource management. Based on the results of the MERIT project. CEH, Wallingford, UK.

Henriksen H.J. (Ed.) (2004) *Test of Bayesian Belief Network and Stakeholder Involvement*, Ministry of Environment Geological Survey of Denmark and Greenland (GEUS) pub. (www.geus.dk)

Castelletti, A. and Soncini-Sessa R. () Topics on system analysis and integrated water resources management. Elsevier book. Chapter 3.

Development: The system developed by five MERIT's partners: Centre for Ecology and Hydrology (CEH), the Department of Computer Science, Institute for Electronic Systems, Decision Support Systems Group, Aalborg University, Denmark; the Ministry of Environment, Geological Survey of Denmark and Greenland (GEUS); the "Universidad de Castilla la Mancha" (UCLM), Spain; the "Sperimentale Italiano Giacinto Motta S.p.a", Milano, Italy (CESI). Copenhagen Energy (CE) was involved in the context of the Danish case study as the decision-maker and end-user. MERIT is a research project supported by the European Commission under the Fifth Framework Programme (Contract no.EVK1-CT-2000-00085: June 2001-May 2004).

10.2.5. MONERIS

Primary scope/domain: The MONERIS model (Modelling Nutrient Emission in River Systems) was developed in order to estimate nutrient emissions into river systems from point sources (waste water treatment plants and direct industrial discharger) and six diffuse pathways (atmospheric deposition, erosion, surface runoff, tile drainage, groundwater and paved urban areas).

Technical design: The model is conceptual, not dynamic, and designed for large river basins. It calculates total nitrogen and total phosphorus emissions from point and diffuse sources, riverine retention and resulting loads for single years or as mean for periods. The model uses information on river flow (from gauging stations), water quality (nutrient concentrations from monitoring stations), statistical data (inhabitants, sewer systems, etc.), GIS-related geographical data (stored and analysed in a GIS). It will estimate equilibrium conditions for a hydrological period. The model runs under MS-Excel 2000 or later.

Support provided: MONERIS can help managers identify proportion of pathways on the total nutrient emissions and helps to identify those to be targeted for management practices aimed at nutrient emission reduction. Combined with geographic information, it can help identify hot spots within the catchment - particular areas that, due to a combination of high potential emission and a susceptibility to efficient transport, contribute nutrients significantly more than other areas. MONERIS provides several management scenarios to reduce nutrient emissions. For example, a manager can ask by how much nutrient emissions into the river would be reduced under a scenario of erosion control.

Distribution and maintenance: MONERIS runs under EXCEL. The files are freely available by contacting Horst Behrendt at the IGB. The IGB tries to stay in close contact with people applying the model, giving explanations on the model and discussing the results.

Users and applications: MONERIS was applied in the Po River Basin (Artioli Y. *et al.* (2005), Palmeri L. *et al.* (2005)). MONERIS is used by the International Commission for the Protection of the Danube River (ICPDR) and Danube governments to assess nutrient emissions into 388 sub-basins in the Danube River Basin. It is integrated in the Elbe-DSS. MONERIS has been applied to catchments all over Europe. Within the European projects EUROHARP, BUFFER, STREAMS, DANUBS, EUROCATS and Lake Promo or by NATO-CCMS as well as national projects the model has been applied, tested and compared against different input data and other models calculating nutrient fluxes in river systems.

Documentation:

Main scientific papers:

Artioli, Y., Bendoricchio, G. and Palmeri, L. (2005) Defining and modelling the coastal zone affected by the Po river (Italy), *Ecological Modelling*. **184**(1), 55–68.

Behrendt, H. and Dannowski, R. (2005) *Nutrients and Heavy Metal in the Odra River System – Emissions from Point and Diffuse Sources, their Loads, and Scenario Calculation on Possible Changes*. Weißensee Verlag, Berlin, 353 pp.

Behrendt, H., van Gils, J., Schreiber, H. and Zessner, M. (2005) Point and diffuse emissions and loads in the transboundary Danube River Basin. – II Long-term changes. *Large rivers*. **16**(1-2), 221–247.

Palmeri, L., Bendoricchio, G. and Artioli, Y. (2005) Modelling nutrient emissions from river systems and loads to the coastal zone: Po River case study, Italy. *Ecological Modelling*. **184**(1), 37–53.

Schreiber, H., Behrendt, H., Constanttinescu, L. T., Cvitanic, I., Drumea, D., Jabucar, D., Juran, S., Pataki, B., Snishko, S. and Zessner, M. (2005) Point and diffuse emissions and loads in the transboundary Danube River Basin. – I A modelling approach.

Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G. and Uebe, R. (2000) Nutrient emissions into river basins of Germany. *UBA-Texte.* **23**/00, 1-288.

Behrendt, H. and Bachor, A. (1998) Point and diffuse load of nutrients to the Baltic Sea by river basins of North East Germany (Mecklenburg-Vorpommern). *Water, Science and Technology.* **28**(10).

Development: The model was developed at the Leibniz Institute for Freshwater Biology and inland Fisherie Berlin in the Department of Shallow Lakes and Lowland Rivers.

(http://www.igb-berlin.de/weborg/frames_abtlg/igbabtframeset_e.htmlwas). For the development users have not been involved directly.

10.2.6. MULINO DSS

Primary scope/domain: Mulino DSS (also mDSS) is a generic decision support system developed to assist the implementation of the Water Framework Directive and the development of the River Basin Plans. It is applicable to a range of decisions - choices from predefined policy options. The main focus is on selection of measures and development of programmes of measures to meet the WFD objectives. Gaps addressed: lack of operational applicability of the IWRM concept, integration of different aspects of the problem at hand and impacts of proposed policies.

Technical design: The DSS consists mainly of methods and techniques to elicit, scrutinise and aggregate decision preferences. Various multiple criteria decision techniques (such as TOPSIS, OWA, ELECTRE, group decision techniques) are implemented and extended with techniques for sensitivity analysis and sustainability impact assessment. The DSS has interfaces to environmental models so that their predicted impacts can be incorporated in the evaluation and preference elicitation. Interface of the mDSS is built upon the DPSIR framework which guides the problem formulation and exploration. The newly released version mDSS4 is integrated within a framework (NetSyMod, see www.netsymod.eu) which contains various analyses (not encoded in the software) on the results on which the mDSS builds. The integration is facilitated in the policy assessment, taking into account various aspects of the problem at hand.

The current system is distributed in the English language only, an earlier version includes a contextual help in various languages. It requires Windows operational system, starting form Win 2000; ca. 30 MB disk space and 128MB RAM. The version 4 requires MS .NET framework to be installed. The system reads GIS data in SHAPE and ASCI formats. Implementation of OpenMI standard is envisaged.

Support provided: mDSS supports mainly the identification and evaluation of policies, and it builds on insights gained through stakeholders' involvement. The NetSyMod framework on the other hand facilitates collective learning and relationship building, and by doing so increases prospects for compromising different expectations/interests.

Distribution and maintenance: The DSS is freely available; a copy can be obtained form http://www.feem.it/mulino (under the general public license). The system is a stand-alone software working under the Windows (2000, Me, XP) operational system. The system is maintained and further developed by FEEM (www.feem.it).

Users and applications: The system was developed for water authorities dealing with water policies but the use of the software is not restricted to this user group. It was applied in a range of case studies 5 (see http://siti.feem.it/mulino/exesum/exesumm.pdf). Later the system was incorporated also in the Transcat DSS and applied in additional case studies. The software is being used for educational purposes in The Netherlands.

Documentation: The system is distributed with a tutorial (a case study developed with the help of the system), user guide and a description of the methodologies applied (decision guide).

Main scientific papers:

Giupponi, C. (2006) Decision Support Systems for implementing the European Water Framework Directive: The MULINO approach. *Environmental Modelling & Software*, In Press, Corrected Proof.

Mysiak, J., Giupponi, C. and Rosato, P. (2005) Towards the development of a decision support system for water resource management. *Environmental Modelling & Software*. **20**(2), 203–214.

Giupponi, C., Mysiak, J., Fassio, A. and Cogan, V. (2004) MULINO-DSS: a computer tool for sustainable use of water resources at the catchment scale. *Mathematics and Computers in Simulation*. **64**(1), 13–24.

Development: The system was developed by an international research consortium (9 institutions from 5 European countries, see http://siti.feem.it/mulino/home/consort.pdf). The development was funded by the EC under the FP5 (Energy, Environment and Sustainability Development programme, key action water). The development was driven by a close involvement of 13 policy