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An Integrated Assessment Framework for Water Resources Management: A DSS Tool and a Pilot Study Application

Summary

Decision making for the management of water resources is a complex and difficult task. This is due to the complex socio-economic system that involves a large number of interest groups pursuing multiple and conflicting objectives, within an often intricate legislative framework. Several Decision Support Systems have been developed but very few have indeed proved to be effective and truly operational. MULINO (Multisectoral, Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) is a project funded under the Fifth Framework Programme of the European Research and the key action line dedicated to operational management schemes and decision support system for sustainable use of water resources. The MULINO DSS (mDSS) integrates hydrological models with multi-criteria decision methods and adopts the DPSIR (Driving Force – Pressure – State – Impact – Response) framework developed by the European Environment Agency. The DPSIR was converted from a static reporting scheme into a dynamic framework for integrated assessment modelling (IAM) and multi-criteria evaluation procedures. This paper presents the methodological framework and the intermediate results of the mDSS tool through its application in a pilot study area located in the Watershed of the Lagoon of Venice.

Keywords: Integrated water resources management, Spatial decision-making, Decision support system, Catchment, Environmental modelling

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Introduction

Decision making for the management of water resources in highly developed catchments is a complex and difficult task. This is due to the very complex socio-economic systems with different interest groups pursuing multiple and conflicting objectives, and, quite often, intricate legislative and administrative frameworks and constraints imposed at different levels. The intrinsic complexity of conflicting human systems is reinforced by the natural and spatial diversity of catchments with dynamic interrelationships and varied effects both on the human and on the ecological systems. Therefore, decision making for water resource management is quite a challenging issue.

In such a context an increasing role is played by models, computers and information systems that may be useful tools for assisting the authorities in charge of water resource management, in order to settle compromises for water demands of competing sectors, while preserving the quality of the environment.

Water management authorities may take advantage in using computer software, which allows to handle huge amounts of information and to effectively make decisions in complex institutional contexts. The above mentioned systems, designed to support the duties of decision makers (DMs), are generally called Decision Support Systems (DSS) and encompass a very large range of computerised tools based on various methodological approaches and technologies. The scientific and technical literature is particularly rich in proposals of DSS tools for water resource management. Tools have been designed and developed for dealing with specific issues such as prevention and management of water shortages (droughts), surpluses (floods) and qualitative degradation (pollution). DSS such as WATERWARE (Fedra, 1994; Jamieson and Fedra, 1996a; Jamieson and Fedra, 1996b), AQUATOOL (Andreu *et al.*, 1996), NELUP (O'Callaghan, 1995; Dunn *et al.*, 1996), FLOODSS (Catelli *et al.*, 1998), DSSIPM (da Silva *et al.*, 2001), STEEL-GDSS (Ostrowski, 1997), to mention just a few, are examples of computer software developed to face a wide range of problems in different natural environments and at different scales.

However, although the use of DSS technology is broadly acknowledged by a number of scientific publications in different disciplines, the risk of failure of a computerised system for senior executives has been estimated as being higher than 70% (McBride 1997 quoted by Poon 2001), which makes development of DSS tools quite risky. There are several reasons why, despite a huge development effort, these systems have been scarcely used at the management level: the lack of user friendly interfaces, the insufficient involvement of potential end users in software development, a poor identification of user needs, the excessive complexity, and the lack of adequate supporting documentation and tutorials, etc.

The need for improving the DSS methodology and technology in water resource management and their potential for real world application has been identified by the Fifth Framework Programme (5FP) of the European Commission through a key action line dedicated to operational management schemes and decision support systems for sustainable use of water resources at catchment scale. One of the projects funded under this action line, which started in January 2001, is called MULINO (Multisectoral, Integrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale). Out of three DSS prototypes planned, two have already been released and tested.

This paper presents the methodological framework for integrated assessment in water resource management, the structure of the Mulino DSS (mDSS), and its application in a developed for testing pilot case study. The first section presents the methodological background for the design of the DSS to assist water authorities in the management of water resources. The second release of the DSS (mDSS2) is presented in the following section, while its application in a pilot study area located in the hydrological basin surrounding the Venice Lagoon (Italy) is described in the last section, in order to provide a deeper insight on the functionality and applicability of the tool.

From an environmental reporting framework to an integrated assessment system

Environmental reporting has been gaining momentum over the past decade as an important tool for monitoring and evaluating the state of the environment and its changes during time (e.g. atmosphere, land, water and biodiversity). Examples are the volumes published worldwide every year about the state of the environment (EEA, 2000).

Prerequisite for the assessment and reporting on the state of the environment and its evolution as affected by human activity is the identification of adequate sets of indicators to be surveyed and a functional scheme to describe the cause-effect linking the state of the various –ecological, economic, social, technological– indicators.

Relevant examples in this field are the PSR scheme (Pressure – State – Response), adopted by the Organisation for Economic Co-operation and Development (OECD, 1994), the DSR system proposed by the Commission on Sustainable Development of the United Nations (UN, 1997) and the DPSIR framework (Driving Force – Pressure – State – Impact –Response), developed by European institutions: the Environmental Agency and Eurostat (EEA, 1999).

The DPSIR framework was developed for environmental reporting purposes and structures the description of the environmental problems by formalising the relationships between various sectors of human activity and the environment as causal chains. This framework aims at making explicit the cause-effect relationships between interacting components of complex social, economic and environmental systems and at organising the information flow between its parts. The environmental management process is described as a sort of feedback loop controlling a cycle consisting of five stages (see Figure 1a):

- *Driving forces* are the underlying causes which lead to environmental pressures. Examples are human demands for agricultural land, energy, industry, transport and housing.
- These driving forces lead to *Pressures* on the environment, for example the exploitation of resources (land, water, minerals, fuels, etc.) and the emission of contaminants.
- The pressures in turn affect the *State* of the environment. This refers to the quality of the various environments (air, soil, water, etc.) and their consequent ability to support the demands placed on them (e.g. supporting human and non-human life, supplying resources, etc.).
- Changes in the state may have an *Impact* on human health, ecosystems, biodiversity, amenity value, financial value, etc. Impact may be expressed in terms of the level of environmental harm.
- The *Responses* demonstrate the efforts of society (e.g. politicians, DMs) to solve the problems. E.g. policy measures, planning, actions in general.

Within this framework the task of decision makers is hence that of analysing the territorial system and assessing the acting Driving forces, their Pressures, the consequences on State variables and their ultimate Impact. From the assessment of Impacts they should determine appropriate responses, in order to direct the final effect in the desired direction (a reduction in environmental harm). Therefore in a decisional context related to natural resource management, the Impact describes the existing problem arising from the change detected in State variables, usually expressed by environmental indicators, which reduces the value of the natural resource either in quantitative, economic, or qualitative terms.

In theory, DMs who can potentially take advantage of the DPSIR approach, range from high level (national and international) policy making bodies to local management authorities. Driving forces, Pressures and States are the possible levels of intervention, as depicted in Figure 1a: a DM chooses one of them (or a combination of them) as a concrete object for his response depending on his/her responsibilities and capabilities. In general, local managers should not be able to change the main socio-economic Driving forces, but within their specific jurisdictions they may effectively deal with the State of the environment and with the Pressures. Conversely, the higher level policy making

bodies can act on Driving forces and Pressures, as they do not deal directly with environmental conditions or State (Figure 1b).

[Figure 1 here]

From the above, the potential of the DPSIR approach for decision making in the field of natural resource management should clearly result. Nevertheless the methodology for an effective implementation of a decisional process in the DPSIR framework is far from being trivial as demonstrated by the substantial lack of implementation other than that of environmental reporting. The adoption of the DPSIR scheme in an operational DSS tool (mDSS) required the development of innovative theory and methodologies aimed at transforming a static reporting scheme in a framework for dynamic Integrated Assessment Modelling (IAM) and evaluation procedures.

The implementation of IAM in the DPSIR framework was approached by focusing on its DPS part. D, P and S were considered as explicit formalisations of model parameters and variables: in the case of water pollution models, for instance, D's are the driving (i.e. forcing) variables ruling the behaviour of the simulated system, P's may be expressed as the rates of uses and/or pollution processes and S's are the output variables quantifying the evolution of the catchment system as affected by the considered human activities, pollution sources and processes. Each economic sector and human activity with a potential effect on water resources of a catchment can be represented by one or more DPS chains and their internal causal links may be described by a specific simulation model.

In the context of decision making within the DPSIR framework, the IAM procedures can support the choice among alternative solutions (responses), by providing sets of indicator values deriving from subsequent simulation runs in which model(s) have been parameterised to represent the expected consequences of every considered alternative.

Regarding the evaluation procedures, they have been implemented in the mDSS by focusing on the link between S and I and between I and R and by adapting concepts and methods derived from Multi-Criteria Analysis (MCA) literature (Hwang and Yoon, 1981) and depicted in Figure 2.

[Figure 2 here]

The preliminary phase of Problem Structuring is targeted to the identification of factors or criteria to be considered for choosing among previously defined alternative response options and takes to the delineation of the structure of the Analysis Matrix (AM). Those factors are in fact expressed and quantified by the State variables, whose values derive from IAM or monitoring activities and fill the AM. The step between the quantification of State variables in the AM and the identification of Impact indicators or indices can be conceptualised according to the MCA theory as the conversion of the AM into an Evaluation Matrix (EM), which expresses the estimated impacts. This step is realised by means of normalisation procedures and value or utility functions, allowing respectively the comparison of multidimensional variables and the expression of judgements to convert the scales of state indicators into evaluation criteria specific for the decision in question. The simple standardisation procedure simply transforms any arbitrary data range to a standard interval representing the degree to which a decision objective is matched. The value function is a mathematical representation of human judgements. The way the performances of the alternatives are translated into value scores is controlled by decision maker's preferences. Weights are applied to evaluation criteria to make the preferences of the DMs explicit.

Having identified the impacts as they vary as an effect of alternative response options, the DM –and thus the DSS– has to apply decision rules to the values stored in the EM to identify the preferred option, filling then the gap between I and R. In the simplest case the rule can be expressed by the weighted sum of values stored in the columns of the EM. Various iterations are possible to refine the selection of the preferred response: considering the results of the sensitivity analysis, refining

the weights, or choosing alternative decision rules; parallel procedures are also possible in multi-stakeholder group decision making.

A dynamic Decision Support System within the DPSIR framework: mDSS

The main objective of the MULINO project is to contribute at improving decision making in water resource management at the catchment scale, in compliance with the EU-Water Framework Directive. The DSS under development integrates hydrological and socio-economic models with multi-criteria decision methods in order to assist water authorities in the management of water resources. In doing so the project focuses on the needs of six European case studies, coping with real problems and issues arising from varied and conflicting water uses and demands.

The decisional cases are formalised as sets of alternative response options, among which the decision maker chooses the best one on the basis of a common list of criteria extracted from indicator values (D, P, or S) provided by various data sources and in particular by model simulations implemented to estimate the expected effects of the various options under evaluation. The DPSIR framework in its dynamic formulation through the implementation of alternative response options represents therefore the common denominator of the different case studies, offering a great potential to instruct and lead the DM through the decision problem and to transparently report the decision process.

Three decision phases were adopted (Simon, 1960), as depicted in Figure 2. In the first, *Conceptual or Problem Formulation Phase*, the DM is concerned with the identification and decomposition of the problem and the organisation of the objectives. The second, the *Design Phase*, includes detailed analysis of the problem to understand its general nature and extent by establishing the cause and effects relations. Feasible options are designed and decisional criteria defined. Finally, in the third phase called *Choice Phase*, the DM considers the impacts of alternative options along multiple dimensions in order to choose the best course of action to solve the problem.

[Figure 3 here]

Conceptual phase: problem exploration

The DPSIR approach allows the end user to conceptualise, structure and communicate the decision situation according to the cause-effect relationships, inherent to the environmental problem(s). The DPSIR framework supports the DM through the decision process by facilitating the exploration of problem, which can usually be described as an Impact; i.e. a negative phenomenon or event observed in the real world, whose mitigation may be under the competences of the DM. The observation of an Impact usually induces the DM to investigate the possible causes, by means of a backward process that leads to the identification of the most likely Driving Forces. Relevant for an operational implementation of the mDSS tool is the fact that the formalisation of DPS chains implies the conceptual description of the territorial system – a sort of “virtual catchment” – and its main local issues upon which present, but also future decisions can be based.

This phase represents therefore the start of the decision process, after which the main concerns are usually the identification of suitable model(s) and the search of data in the context of the specific decision. The collected information is then organised in the form of indicators in tabular or geographical formats allocated to the nodes of DPS chains and finally the problem is formulated.

Design phase: option definition and modelling

In the following phase, the possible options – responses in terms of the DPSIR framework – are defined and criteria aiming at the evaluation their performance identified, on the basis of available indicators. Subsequently, the options’ performance in terms of the criteria scores is modelled. The hydrological models can be implemented in the mDSS2 through a generic interface which supports a coherent management of Drivers, Pressure and State indicators, as distributed (in space and time)

catchment variables. Subsequent developments are planned to produce a third version of the software (mDSS3) in which simplified models or metamodels are fully coupled within the DSS routines as modelling modules to be activated through a graphical representation of the cause-effect links of the DPS chains. This third version will give full independence to users as it will be able to fully couple simplified models specifically designed for the local situation.

As previously stated, the variables relevant for decision making, either coming from model outcomes or other sources, are organised in an analysis matrix, which contains the performances of the alternative options evaluated for each decision criterion. At this stage the raw performance measured with different units and/or scales across the criteria is determined and then, in the following phase, multiple criteria analysis is carried out.

Choice phase: Multi-criteria decision analysis

The choice (and subsequent implementation of the chosen option) is the final phase of the decision making process adopted for mDSS. Once the criteria for evaluation are determined, the options are individually assessed to gauge their ability to solve the problem. All options are then compared and valued against their impacts using Multi-Criteria Analysis (MCA) evaluation techniques.

The main aim of MCA is to reduce “multidimensionality” of decision problems – the multiple option performances - into a single measure enabling an easy ranking. The heart piece of any MCA decision rule is therefore an aggregation procedure. Decision rules aggregate partial preferences describing individual criteria into a global preference and rank the alternatives. There is no single method universally suitable for all kinds of decision problems; the decision maker has to choose the method which best fits his purpose. Very popular decision rules are those based upon additive aggregation, using criteria weights to give emphasis on more important criteria. The decision rules chosen for implementation in the mDSS software are (i) *Simple Additive Weighting* (SAW); (ii) *Order Weighting Average* (OWA) (Jiang and Eastman 2000) and (iii) the *Technique for Order Preference by Similarity to Ideal Solution* (TOPSIS) (Hwang and Yoon, 1981).

SAW is the most popular decision methods because of its simplicity. It assumes additive aggregation of decision outcomes, which is controlled by weights expressing the criteria importance. OWA is being used because of its potential to control the trade-off level between criteria and to consider the risk-behaviour of the decision makers. Ideal point methods like TOPSIS order a set of alternatives on the basis of their separation from the ideal solutions. The alternative that is closest to the ideal positive solutions and farthest from the negative ideal solution is the best one. These decision rules cover a wide range of decision situations for which they may be applied. The result of decision rules is an alternative option which is recommended to be implemented.

Sensitivity analysis (SA) follows, to examine how robust the final choice is to changes of uncertainty in indicators' values. The main concern of the sensitivity analysis is oriented to the uncertainty addressing the criterion weights. The mDSS tool utilises two approaches for SA: (i) the *Most Critical Criterion* table, allowing the identification of the criterion for which the smallest change of current weight may alter the current options ranking; and (ii) the *Tornado Diagram* that compares graphically each option and shows ranges within which the parameters vary and affect the ranking order.

In response to the end users' request, who increasingly face the demand for public involvement in decisional processes, mDSS2 is equipped with simple tools to face situations in which several decision makers or different stakeholders are involved. The first approach to solve group decision problems is *Behaviour Aggregation*, by means of which the group members are helped to find a compromise and to agree on a common system of objectives and preferences, which lead to an unambiguous solution acceptable to all group members. In the second approach, which is applied when the first fails, a group aggregation function is applied in order to aggregate (and compromise) the different expectations.

For the sake of concreteness, the application of the mDSS2 prototype to a pilot study in the area of the Venice Lagoon Watershed (VLW, north-east Italy) is presented in the next section; mDSS2 has

been applied to support a recent decision problem of a water management authority (the Destra Piave Reclamation Board) in the Vela catchment.

A pilot study application in the Venice Lagoon Watershed

The Venice Lagoon and its watershed form a vast environmental system of approximately 2 500 km², where historical and recent cities, large and medium-small industrial districts and intensive agricultural activities coexist within a peculiar natural area. The drainage basin consists of a low-gradient floodplain with a surface of about 2 000 km². It is drained by water courses with different hydraulic regimes (natural, mechanical, alternate mechanical). About 40% of the basin surface is below the mean sea level and is under reclamation by pumping machines. The pollution discharged into the Venice Lagoon by the rivers streams and canals flowing through the above described catchment represents a relevant contribution to the overall pollution budget of the Lagoon and is a main environmental issue.

In Italy public funds are made available by specific national and regional regulations in order to support the realisation of initiatives for the abatement of pollutant loads that travel from the catchment into the lagoon. In particular, the Special Law for Venice (L. 171/73) defines measures aimed at protecting the city and its lagoon and confers the allocation of funds to the Regional Administration. To apply for those funds, local agencies in charge of water management can present suitable projects targeted at reducing diffuse pollution in the drainage basin.

One of the recipients of such funds are the Land Reclamation Boards, public administrative bodies made up of all the private individuals who live or have economic activities in a given territory requiring water management (defined according to hydrological and administrative criteria). Their main task is that of managing the water distribution system, protecting the territory from floods, managing and maintaining the public infrastructure for land reclamation and irrigation.

The pilot study for mDSS2 focuses on the choice among alternative environmental engineering operations, such as revitalising and re-naturalising water courses, in order to reduce non-point source pollution (agricultural and other) of surface waters.

The Vela Catchment, 100 km² in size, is located in the Venetian floodplain. In the north, along the spring belt, soils are laying over a deep geologic layer of gravel, while the southern part of the catchment is characterised by deep alluvial soils with various textures. From the hydrologic point of view, the area is thus characterised by varying natural vertical flows of water to the aquifer and a dense surface network of natural rivers and artificial canals. Some areas drain naturally, others, mainly located in the southern part where low lying lands dominate, drain mechanically by means of pumping plants. Intensive crop production (mainly maize), livestock production and fragmented urban areas not yet adequately served by waste water treatment plants act as main driving forces affecting water quality of the Vela catchment, substantially contributing to the overall pollution budget of the Lagoon.

In the problem formulation phase (or *Conceptual Phase*), once the exploration of available indicators for Driving forces, Pressure and State contained in the user's catalogues is concluded, DPS chains representing the problem's underlying cause - effect relationships are constructed (Table 1). Some chains are incomplete, in particular those related to the socio-economic drivers that are relevant for the decision but do not provide significant environmental consequences.

At the end of this phase the problem is described in a cognitive and structured way (DPSI) and the area of interest and relative database inspected. The Impact, i.e. the problem for which a Response is needed, in this case stands in general in the degradation of the Lagoon's ecosystem.

[Table 1 here]

In the *Design Phase*, for the sake of simplicity, only three options were selected to test the mDSS out of an original list of 12 alternative projects:

1. excavation of a tributary, the Meolo River, in order to increase water retention time (EXCAV_MEO). Rivers have the natural capability of diminishing pollutant contents through dilution, deposition and absorption processes, as well as through purification with microbes.
2. plantation of a buffer strip of trees along the riverbank of one of the main rivers of the catchment, the Vallio River, to improve the phytoremediation effect (BUFF_VALLIO). Vegetation filter strips have been identified as a best management practice that has the potential to remove substantial amounts of sediments and nutrients from cropland and urban runoff.
3. redirection of the discharge of an area (153 ha) from the Vallio River into the Candellara Canal, that flows outside the lagoon (DIV_CANDE). This option avoids a certain amount of nutrients to flow in the Lagoon.

The first two operations are mainly intended to increase the capacity of water courses in terms of self-purification, in-stream storage and retention times to obtain a reduction in diffuse pollution, the third simply leads away from the Lagoon a certain amount of pollutants (Figure 4).

[Figure 4 here]

Environmental engineering projects such as revitalising and re-naturalising water courses have a good capacity of reducing pollution loads but can also have other functions such as upgrading the farming landscape and improving the recreational use of rural areas. The decision making process is therefore complicated by this multi-functionality that operates on the territory and that combines hydraulic engineering, natural resources management, recreational activities, etc.

A set of appropriate decisional criteria, ranging from environmental impact indicators to expressions of political will, were subsequently chosen from the list of indicators used to build the DPS chains. The selection of the criteria aimed at determining a scale of preferences that consider the objectives and functions of the Board and that reflect those stated in the regional regulations. For instance, criteria that reflected a possible change in the irrigation availability were considered important.

The estimation of resulting changes of indicator values lead to the effectiveness assessment of the three alternative options: first the performances of each criteria were calculated and stored in the Analysis Matrix (Table 2), then each criterion score was translated into a value score that made explicit, through appropriate value functions, the DM's preferences, and therefore the degree to which the main goal was matched by each alternative option. These operations led to taking the decision process a step further: the *Choice Phase*.

[Table 2 here]

Decision problems involve criteria of varying importance. Criterion weights, that provide information on the relative importance of the considered criteria, were assigned. A vector of weights was obtained using the procedure of pairwise comparison implemented in the software, using the judgements expressed by the Board's technical staff. The reduction of hydraulic risk, the irrigation value and the financial constraints resulted as the most important parameters for the ranking of the alternative projects.

Once the weights are defined, the evaluation criteria are aggregated by means of a specific decision rule. This is the procedure by which criteria are selected and combined to arrive at a single final score for each option, and by which evaluations are compared. The Simple Additive Weighting (SAW) method was the first chosen for testing mDSS2. Using the preferences expressed by the Board, DIV-CANDE (diversion of the discharge of part of the catchment through the Candellara canal with outlet outside the Lagoon) resulted to be the most suitable option. A sensitivity analysis carried out on the results of the SAW decision rule enabled the exploration of the options' performances. It was observed that a small increase in the weight of "Nitrogen organization with buffer strips" (from 0.04 to 0.14), lead to a change in the option's rank order by reversing the best

with the second best option (BUFF_VALLIO). Therefore, the choice of the option recommended by the SAW method using the Board's criterion weights resulted neither very robust nor stable, and this can be observed by the very similar value of the overall performances.

The Order Weighting Average (OWA) required a second set of (order) weights that allow to control the trade-off level between criteria and that describe the risk behaviour of the decision maker. The order weights are not assigned to the criteria, but to the position of the rank order defined by the criterion values of an option. According to this, the first order weight is assigned to the criterion with lowest outcome value and the last order weight to the criterion with highest outcome value for an option. To test the method, four sets of order weights were applied to the 15 criteria:

the order weights [0, 0, 1] assign extreme importance to the 5 highest criterion scores (0.2 each). This yields an aggregation operator with a moderate degree of trade-off between criteria and a high degree of ORness, representing the most risk-taking behaviour.

The order weights [0,1,0] assign extreme importance to the 5 middle-ranked criterion scores. This yields an aggregation operator with a moderate degree of trade-off, as well as of ANDness and ORness.

The order weights [1, 0, 0] assign extreme importance to the 5 lowest criterion scores. This yields an aggregation operator with a moderate degree of trade-off between criteria and a high degree of ANDness, representing the most risk-adverse solution.

The order weights [0.5, 0, 0.5] assign same importance to the highest and lowest criterion scores (0.1 each). This yields an aggregation operator with substantial trade-off and a moderate degree of ANDness and ORness.

Order weights [0.33, 0.33, 0.33] apply equal importance to all criterion scores (a weight of 0.066 each) and thus don't change the existing ranking order: the result is equivalent to that of the SAW rule, for which full trade-off is allowed.

As a result (Table 3), the option DIV_CANDE is the preferable one in most of the cases and EXCAV_MEO the least desirable. BUFF_VALLIO stands up as the best option in the case of a risk-averse behaviour. This is due to the fact that greater significance is given to criteria related to self-purification capacity value of the options.

[Table 3 here]

The Ideal point methods order a set of alternatives on the basis of their separation from the ideal and negative-ideal solutions. The ideal solution represents a hypothetical alternative that consists in the most desirable level of each criterion across the options under consideration. The negative-ideal solution consists of the least desirable level of the options' performance. The best alternative is the one closest to the ideal point and most distant from the negative-ideal solution. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the most popular compromise methods. This method's outcome is different from those of the previously presented decision rules, as it indicates BUFF_VALLIO as the best option, confirming the very close performance of two of the three options (as demonstrated also by the sensitivity analysis). Furthermore the TOPSIS method goes beyond the simple closeness to the ideal solution by considering the closeness to the less desirable solution as well.

In view of testing every capability of the software, a simulation of group decision making was also performed. A parallel assignment of weights was carried out with a group of students simulating an environmentalist group: higher weights were assigned to criteria relevant for the environment and the landscape (e.g. nitrogen organication through buffer strips). In general criteria linked to the processes involving a natural reduction of nitrates were assigned higher weights.

As a result, the SAW method gave the plantation of buffer strips along the Vallio river (BUFF_VALLIO) the best ranking score. The problem understanding and preferences of the considered two groups were different, but assuming they were willing to come up with a compromise solution, the very simple group decision making capability of mDSS helped finding a

common final solution. The Borda technique is a very simple algorithm implemented in mDSS2, which assigns ranks to decision alternatives based on the rationale that the higher the position of an alternative plan on the voter's list, the higher the rank assigned. DIV_CANDE is the compromise solution in this case.

Conclusions

The MULINO DSS combines scientific research with real world decision support needs. This application driven approach is reflected by the mDSS software being tested on concrete case studies, each with its particular decision case and cultural, socio-economic and environmental characteristics.

One of the main aims of the project is in fact that of making scientific inputs and assessments useful and usable for decision making, without compromise in scientific rigour, through the creation of an operational application package. Intermediate project results obtained with the implementation of mDSS produced useful outcomes, including the beneficial support to integration across disciplines and communication between scientists and decision makers in dealing with the complexity of local water resources management problems.

As an example, the decision-making context of the pilot case study presented above clearly identifies the situation within which the problem of real decisional support is set: an authority exists (Land Reclamation Board) that can access to regional funds by submitting projects that must respond to predetermined requisites and has the problem of setting up a method that can first identify alternative solutions and then evaluate them to identify which to submit to the funding authority (Veneto Region) that must judge them within the context of funds allocation. In particular, the results of this application demonstrate the potentials of the mDSS tool both in problem exploration and in collaborative multi-criteria analysis while supporting the activities of an operational institution in the process of planning projects and building consensus both within and outside the agency.

The second release of mDSS, resulting from the development of a first prototype presented to project end users in a dedicated meeting and tested in the above pilot study, provides routines for guiding the decision maker in the process of implementing the decisional context into the DSS and for the integration of spatial and temporal data in a MCA evaluation process. MCA has a great potential in aiding prioritisation among alternative solutions. It uses methods that are robust from a logical-mathematical point of view. They are also easily documented so to appear transparent and understandable to the different players involved in the decisional process.

Feedback from potential DSS users has contributed to a substantial improvement of the first prototype, e.g. group decision making capabilities, assisted weighting procedures and sensitivity analysis routines. The early involvement of end users has produced substantial revisions of the original development plans. The chosen strategy - from loose coupling of complex models to full coupling of simplified (meta) models - was considered to present stronger potential for mutual benefit between the research consortium and the involved water management bodies during the development and application of mDSS2, while the simplified and limited, but more targeted tool, allowing the substitution of alternative modules, was considered to increase the possibilities of broader applications of mDSS3 after the end of the research project.

The DPSIR framework, adopted as a core analysis and communication component of mDSS, guides the decision maker through the decision process and allows him/her to construct the main cause-effect relationships underlying the modelled decision problem and, in doing so, facilitates communication within and outside the decisional bodies. The framework proved to be general enough to deal with various decision problems allowing the implementation of different case studies. Despite the DPSIR framework's simplicity, designed for static environmental reporting purposes, its adaptation and transformation into a framework for dynamic integrated assessment modelling procedures required the development of innovative contents and methods not free of

drawbacks: the practical conceptualisation may be ambiguous (for example, the distinction between Driving Forces and Pressures may depend on the application context), making the use of the tool not effortless and time-consuming without previous introductory training.

This effort of combining methodology and “user-friendliness” requires a learning investment from the potential user and therefore a true interest and willingness to use the tool is compulsory. Appropriate documentation and guidelines are being edited and represent one of the main tasks of the future development of the project.

The strategy for future development of the DSS tool foresees the refinement of the final version (mDSS3) that will fully integrate hydrological (meta)models utilising an evolved version of the DPSIR approach and that will provide an extended capability to deal with uncertainty and group decision making. Special attention is given to the software’s interaction with the user, who may be more or less trianed and experienced, both in terms of interface and in terms of training documentation and guidelines, with the aim of achieving a final robust and operational tool with good potentials for practical use outside and after the end of the MULINO research project.

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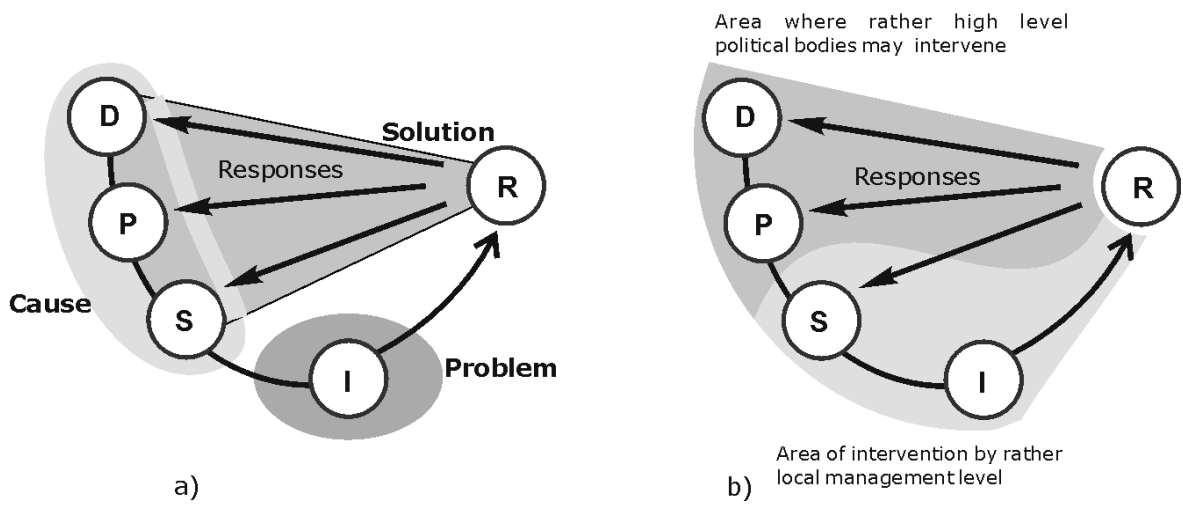


Figure 1. a) The DPSIR framework, a common conceptual that allows the end user to conceptualise and structure the decision situation according to the cause-effect relationships. b) Levels of intervention ranging from policy makers to local management authorities.

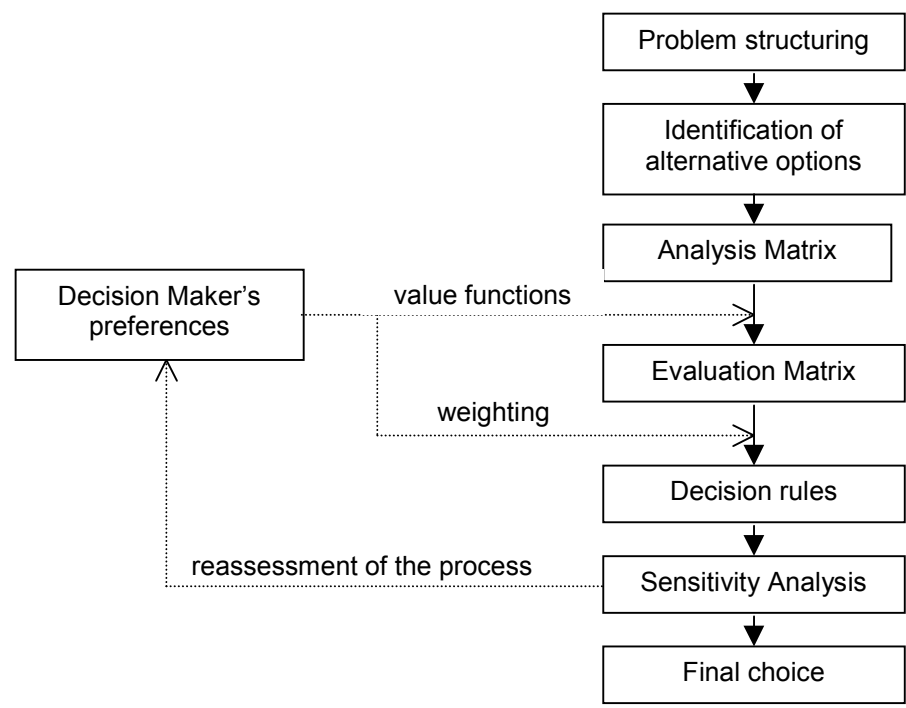


Figure 2. The basic steps of the MCA analysis implemented in the mDSS.

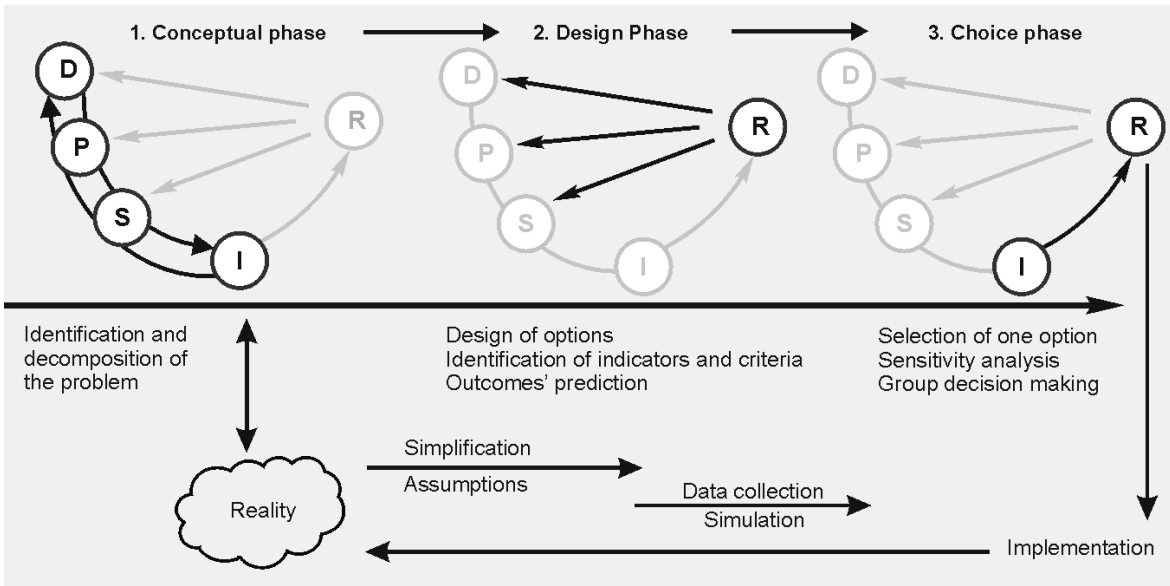


Figure 3. Systematic approach supporting the mDSS, based on Simons' phases of decision process

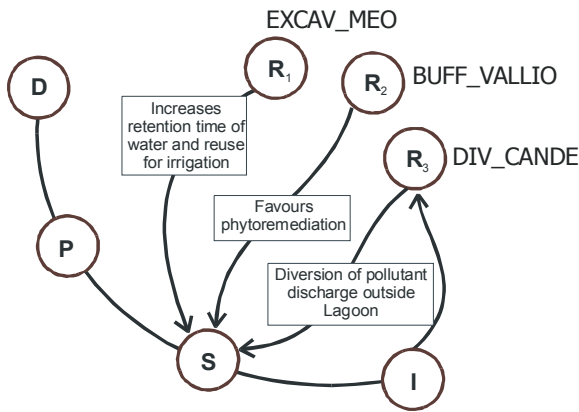


Figure 4. Set of alternative responses that may improve water quality of the Vela catchment.

<i>Driving Force indicators</i>	<i>Pressure indicators</i>	<i>State indicators</i>
D: Urban settlements (inhabitants/km ²)	P: Urban net emission of BOD ₅ (t/yr)	S: BOD/COD in rivers (mg/l)
D: Impermeable (developed) areas (ha)	P: Loads of hazardous substance to water bodies by sector (tHS/yr)	S: Hazardous substances (pesticides) in rivers (µg/l HS)
D: Irrigated land (ha)	P: Use of water for irrigation (m ³ /yr)	S: N organication with irrigation (t/yr)
D: Buffer strips (ha)	P: Drainage water interception by vegetation (m ³ /yr)	S: N organication with buffer strips (t/yr)
D: Use of nitrogen fertilisers in agriculture (kg/ha/yr)	P: Nitrogen balance: total surplus from fertilisers and manure applications (kg/ha/yr)	S: Nitrate concentrations in water bodies (mg/l)
D: Land reclamation by pumping machines (m ³ /yr)	P: Hydraulic risk: return time (yr)	S: Flooding damages (MEur)
D: Land reclamation by drainage network (m ³ /yr)	P: Total discharge of nitrogen (t/yr)	S: Self-remediation of water bodies: N retention (t/yr)
D: Land reclamation by drainage network (m ³ /yr)	P: Surface water drainage (mm/yr)	S: Water retention time (hrs)
D: Social conflicts (index)		
D: Bureaucratic pressure (index)		
D: Variation of social welfare (index)		
D: Local legislation (index)		
D: Public investments (MEur)		
D: Maintenance costs (Eur/yr)		

Table 1. DPS chains for the Vela catchment.

<i>Criteria</i>	<i>buff valli</i>	<i>div cande</i>	<i>excav meo</i>
D: Impermeable (developed) areas (ha)	2.716	0.000	0.000
D: Use of nitrogen fertilisers in agricult	0.876	0.004	1.171
S: Water retention time (hrs)	3.500	0.000	3.000
S: Self-remediation of water bodies: N ret	0.338	9.839	0.170
S: N organication with irrigation (t/yr)	1.664	0.000	33.281
S: N organication with buffer strips (t/yr)	15.000	0.000	0.000
D: Urban settlements (inhabitants/km ²)	2.005	0.000	0.000
D: Social conflicts (index)	0.000	1.000	0.000
D: Bureaucratic pressure (index)	0.132	0.075	0.034
D: Variation of social welfare (index)	0.067	0.127	0.057
D: Maintainance costs (Eur/yr)	0.042	0.079	0.074
D: Local legislation (index)	0.032	0.167	0.085
P: Use of water for irrigation (m ³ /yr)	100.000	0.000	2 000.000
P: Hydraulic risk: return time (yr)	0.022	0.149	0.072
D: Public investments (MEur)	300.000	250.000	200.000

Table 2. Analysis matrix built with criterion indicators extracted from the DPS chains reported in Table 1.

<i>Order weights</i>	<i>Div Cande</i>	<i>Buff Valli</i>	<i>Excav Meo</i>
[0, 0, 1]	0.086	0.074	0.07088
[0, 1, 0]	0.0204	0.0099	0.00876

[1, 0, 0]	0.00016	0	0
[0.5, 0, 0.5]	0.043	0.03708	0.03544

Table 3. Final scores resulting from application of different sets of order weights in the OWA rule.

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- (lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
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- (lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
- (lxiii) This paper was presented at the ENGIME Workshop on “Social dynamics and conflicts in multicultural cities”, Milan, March 20-21, 2003
- (lxiv) This paper was presented at the International Conference on “Theoretical Topics in Ecological Economics”, organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
- (lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
- (lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL), Venice, August 28-29, 2003
- (lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
- (lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
- (lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003
- (lxx) This paper was presented at the 9th Coalition Theory Workshop on "Collective Decisions and Institutional Design" organised by the Universitat Autònoma de Barcelona and held in Barcelona, Spain, January 30-31, 2004

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