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Decision Support for Water Resource Management: An Application Example of the MULINO DSS.

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Abstract: MULINO is an EU RTD project, funded under the FP5-EESD programme. It aims at providing a Decision Support System (DSS) targeted at solving decision problems in the management of water resources. Through the integration of socio-economic and environmental modelling techniques with geographic information system (GIS) capabilities and multi-criteria decision aids, the MULINO-DSS aspires to be an operational tool which meets the needs of European water management authorities and facilitates the implementation of the EU Water Framework Directive. The application-driven approach to developing the MULINO-DSS combines the scientific background of the consortium members with local knowledge and decision support needs, expressed by five user groups. The diversity of cultural, socio-economic and environmental characteristics of the case studies requires that the tool is capable of a common approach to different decision cases but also flexible enough to adapt to the specific objectives and constraints of a given decision problem. The DPSIR framework (Driving forces – Pressure – State – Impact – response) has been chosen as the overall conceptual framework of the DSS. A demonstration of the first MULINO-DSS prototype is presented through an application example in the Vela catchment that belongs to the Venice Lagoon Watershed (north-east Italy). The decision act refers to the choice among alternative actions (public works) for the improvement of Vela's water quality.

Keywords: Water resources; Decision Support System; Catchment; Modelling

1.   INTRODUCTION

Demand and competition for water resources continue to increase in Europe. Many efforts have been made at local, national and European levels to regulate the uses of water in order to mediate between conflicting demands. In a broader sense, to promote sustainable water use so that future generations will be able to meet their own needs. The European Union has recently issued the "Council Directive establishing a framework for Community action in the field of water policy" (2000/60/EC), known as the Water Framework Directive (WFD) [EC 2000], which identifies common principles towards which Member States will have to orient their efforts. Both principles for the management of economic aspects, such as "full cost recovery" and guidelines for the management of planning aspects, such as "catchment based management" are described. Territorial management based upon physical rather than administrative boundaries represents an innovation in procedure for many countries. EU member states are bound to achieve "good ecological status" for water bodies by the year 2015. The coming years will therefore be crucial for Europe's re-orientation in its approach to water management, this also being one of the main challenges of the process of continental harmonisation and unification.

Many decision support systems have been developed to face the problems of water-resource management. The need for a computerised decision support system (DSS) is clearly emergent as a result of the increasing complexity of the decision situations caused by the numerous conflicting, often spatially related objectives, and the dissimilarity of stakeholders involved. However there are still open methodological questions about the development and structure of operational

DSS's, with and for European decision makers (DM) in the field of water resource management.

In the context of the implementation of the WFD and in the mainstream of related decision technology, a 3 - year project named MULINO[1] was launched at the beginning of 2001, within the 5th Framework Programme of the EU [Giupponi at al. 2001]. A primary challenge for the project is to produce a tool that is capable of modelling the hydrological system that effects the state of water resources in a given catchment. Furthermore it is necessary to develop a user interface that allows a step by step approach to evaluating the sustainability of water use options.

The involvement of water managers from five European countries, each working within their own local legislative framework, and with their own geographical context serves two purposes. Firstly, it creates conditions that will favour the development of a robust tool - a decision support system that is responsive in a range of cultural, political and organisational contexts. Secondly the involvement of these individuals serves to involve the administrators and decision makers in a process that is linked to the evaluation and understanding of the new European water policy.

This paper presents the background development of a decision support system which is under development by the MULINO Consortium. The first version of the DSS tool is presented, together with the results of its experimental application in a simplified case study. The outcomes are discussed in view of the planning of project activities, in particular, the development of the future DSS versions, in collaboration with an European panel of potential end users.

2. MULINO-DSS UNDELYING DESIGN

A common structure has been designed for the MULINO-DSS, integrating hydrologic, socio-economic and environmental models in a multi-criteria analysis tool.

The DPSIR framework (Figure 1), (Driving force-Pressure-State-Impact-Response), developed by the European Environment Agency [EEA 2000] was chosen as the underlying conceptual framework of the MULINO DSS software. The DPSIR approach is aimed at analysing the cause-effect relationship between interacting components of complex social, economic and environmental systems and in managing the information flow between its parts. In the MULINO-DSS context it is used to represent the conceptual procedures for understanding, modelling and managing the decisional issues associated with water resource management. By taking this framework as the structure for the DSS software, water managers will have the means to conceptualise individual situations in a common way and take advantages from the European initiatives in the field of environmental management and reporting.

The *driving forces* are represented by natural and social processes which can lead to environmental problems, e.g. energy, agriculture, industry and waste management. The *pressure indicators* are outcomes of the driving forces, which influence the current environmental state. A common expression of this is the use of resources: representing an input for a variety of natural processes and leads to the changes of the environmental condition. *State indicators* describe physical, chemical or biological phenomena in the given reference area. They may describe the land uses or their current condition (forest health). *Impact indicators* refer to the consequence of an environment state change. The result of an impact, such as air pollution, is followed by many effects (global warming, loss of biodiversity) at various temporal and spatial scales (extinction of same animal species).
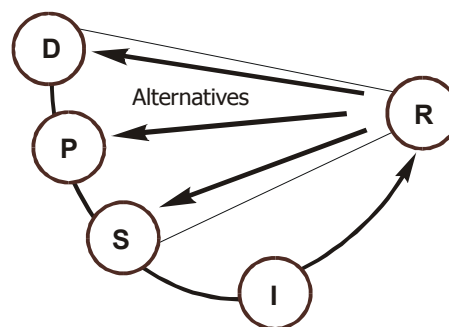

Figure 1: DPSIR framework: (D) Driving force; (P) Pressure; (S) State; (I) Impact; (R) Response.

The DPSIR has been extended by the concepts of decision making (options, criteria and evaluation) in order to provide a common structuring support for the MULINO-DSS. In this context the DPSIR approach can support the DM by introducing a structural system of the catchment in which cause-effect chains are formalised and eventually modelled to simulate the expected effects of the proposed courses of action (responses to water management issues). Through the analysis of possible options the MULINO-DSS user will create a record that documents the decision process

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[1] MULINO - MULti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale

demonstrating the priorities that guide decision making.

From the decisional problem point of view, the Impact highlights the imminent problem given the current characteristics' differ from those desired. The negative Impact arises as the change of the environment state reduces the available quantity or quality of the natural resource. The Response refers to the decision act, choosing a possible alternative, an activity aimed at the reduction of the negative pressures on the state of the environment. The Driving forces, Pressures and States can be considered as alternative references: a decision maker can choose one or a combination as a concrete subject for his response., depending on his/her competence and authority.

3. MULINO–DSS DELOPMENT

The first version of the MULINO-DSS has been

designed to support a single decision maker, and (iii) the software is not yet designed for dealing with the uncertainty of the decision outcomes.

The MULINO-DSS distinguishes two roles during the decision process: the manager's role and the role of a technician. The emphasis of the manager's role is included in the initial and final phases of the decision process. In the first phase he deals with the conceptual structuring of the decision problem and explores the available data and/or monitored environmental indicators, useful in describing important decision aspects. The results are expressed in preliminary DPS (first part of the DPSIR, which includes driving forces, pressures and states) chains providing the causes of the problem. The set of feasible options is also indicated by the manager. In the next phase, when the decision model is built, the technician is responsible in determining the underlying concrete models to the identified DPS chains and calculates expected decision outcomes of the options. In the
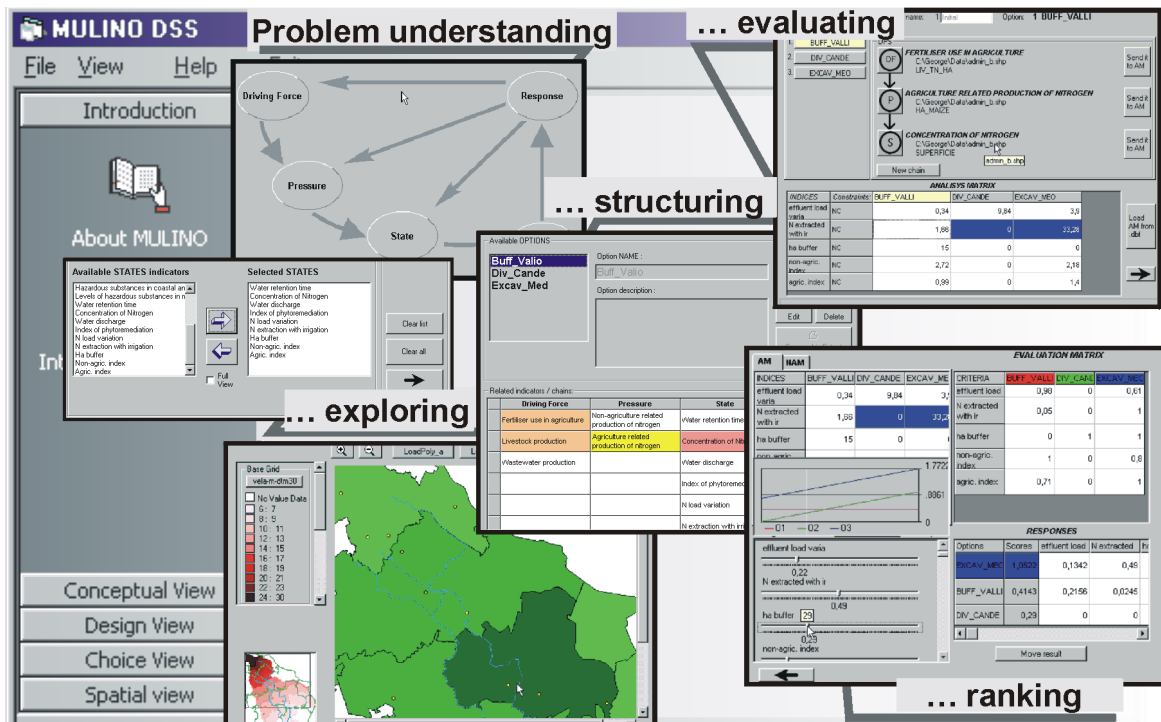

Figure 2: Process of decision making within the MULINO-DSS; from problem understanding through spatial database exploring and problem structuring to the modelling and aggregation of decision preferences.

recently released and tested (Figure 2). The MULINO-DSS first release is aimed at supporting the decision process mainly through the suitable structuring of the decision problem and through preference modelling. The released version is characterised by following constraints that will be progressively overcome in the next two versions: (i) the software provides no dynamic modelling routines, but is designed to work on top of external modelling and GIS; (ii) the software is the final

phase, resulting in the choice of a preferred solution, the manager collaborates with the technician during the preference modelling and aggregation.

The second MULINO-DSS release will loosely integrate a comprehensive hydrological model, whereas the third release will tightly integrate simplified (or meta) models derived from those used for the project case studies.

4. AN APPLICATION EXAMPLE OF MULINO-DSS FIRST RELEASE

The decision problem from the Vela case study, located in the watershed of the Venice Lagoon (north-eastern Italy), was adopted to test the MULINO-DSS first release. The problem to be solved was taken from a decisional case that involved one of the local water management authorities, the Destra Piave Land Reclamation Board. The main objective of the following study was to test the methodology developed for the MULINO-DSS in its suitability to deal with real decision problems. The experience from this test will be taken into consideration in the subsequent MULINO development. For this reason the case study was focused at the conceptualisation and design of the decision problem rather than at the selection of the best solution.

The decision problem was concerned with the choice among alternative proposals for the realisation of public works in the drainage network of the Vela Catchment, to be submitted for financing to the Veneto Regional Administration. These alternative projects are all related to the conservation and safeguarding of the Venice Lagoon: diffusion of pollution from agricultural sources, in terms of nutrient loads (mainly nitrogen), is the main environmental issue, for its consequences both within the Vela catchment and, downstream, in the Venice Lagoon ecosystem. Industry and the density and distribution of the population are the other drivers responsible for the discharges of a variety of pollutants to the catchment waters (Figure 3).
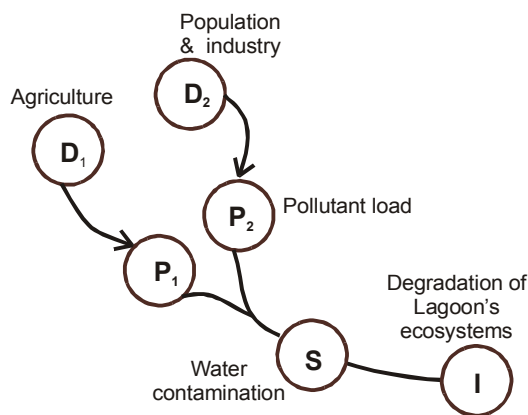

Figure 3: Cause-effect relationships causing the environmental problem in the Vela case study.

The decisional problem was formulated as follows: what is the best set of projects that (i) meets the various decisional criteria expressed by the various actors involved; (ii) maximises the environmental benefits according to the environmental impact assessment approach; (iii) utilises the entire available budget.

A preliminary list of possible projects were at first determined and then evaluated, in order to identify which could be submitted. A set of decisional criteria, ranging from environmental impact indicators to expressions of political will, were subsequently chosen and were used to evaluate the different projects. The option outcomes used for evaluation describe how the catchment's hydrologic system responded to the alternative solutions.

Within the list of alternative projects, three were selected to test MULINO-DSS (Figure 4):

1. excavation of a tributary, the Meolo river, in order to increase the water retention time (R_1).
2. plantation of a buffer strip of trees along one of the main rivers of the catchment, the Vallio river (R_2).
3. redirection of the discharge of an area from the Vallio river into the Candellara canal that drains outside the lagoon (R_3).
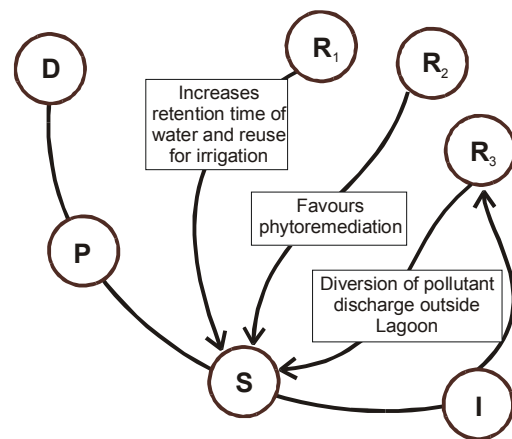

Figure 4: Identified responses improving the environmental state of Venice lagoon in the Vela case study.

The options are not aimed at reducing environmental pressure but act directly on the state of water resources. Indices of pressure were considered to be important as they give an indication of the risk level of heavy water pollution at the subbasin level: the higher the pressure of human activity in the area of interest, the higher the importance of an action that mitigates nutrient contamination. Two indicators, describing pollution loads from the two categories of sources, agricultural and non-agricultural, were calculated to represent the pressure in the various sub-basins of the Vela Catchment.

The alternative courses of action influence the *state* of the Vela waters in different ways: (i) varying amounts of nitrogen that can be removed through

the self-purification capacity of rivers, (ii) through the phyto-remediation effect of buffer strips or, (iii) by simply leading away a certain amount of water from the lagoon.

The reduction of the negative impact (amounts of nitrogen not discharged in the lagoon) obtained by the implementation of alternative options describes effectiveness of available solutions. In order to make the options comparable, each option outcome was translated into evaluation indices that represented the degree in which the main goal was matched.

In the original case study a wide set of criteria organised hierarchically into five levels was used, whereas in the testing of the tool, only five environmentally-related criteria, aggregated in two macro-criteria, were used for the sake of simplicity. The two macro-criteria respectively evaluated the "loads" of each sub-basin area involved and the "removals" that quantified the purification effect for each course of action (Figure 5).
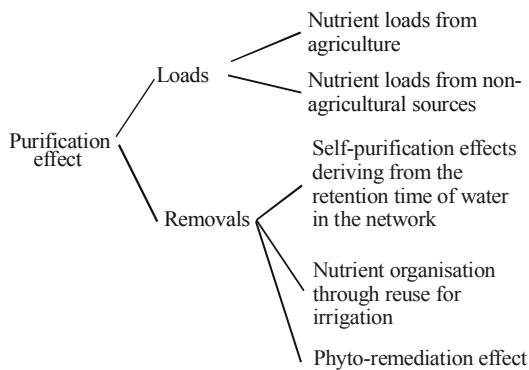
Figure 5: Hierarchical organisation of the decision criteria in the Vela case study.

The *decision matrix* describing the decision problem was built with values deriving from the above mentioned indicators of pressure (nutrient load from agriculture and from sources other than agriculture) and state indices (retention time of water in network, reuse for irrigation and phyto-remediation effect) (Figure 6).

The standardised evaluation criteria were subsequently aggregated. The decision rules selected for the MULINO-DSS first release are those of *Simple additive weighting* and AHP (*analytic hierarchy process*) [Saaty 1980]. Additionally, *Order weighting average* [Jiang and Eastman 2000] and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) have been discussed to extend decisional capability in the subsequent versions of the MULINO-DSS. Simple additive weighting is a popular decision rule because of its simplicity. It uses the additive

form for the aggregation of different criteria outcomes, which assumes the independence of the criterion preference.
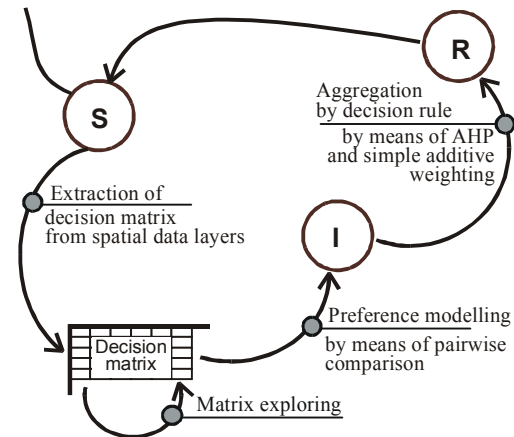
Figure 6: Schematic representation of decision routines implemented in the MULINO-DSS.

The Analytic hierarchy process (AHP) is based on hierarchical additive weighting, employing the *pairwise comparison method* to compare the alternative options and estimate decision weights.

Once the alternative options were ranked, the decision maker could easily choose the most suitable alternative to his decision needs. In this tested version, the excavation of the Meolo river (alternative 1) was considered as the best solution in accordance with the results of the original decision case study.

In view of testing every software capability, the decisional problem briefly described above was also tested with respect to a hypothetical future scenario. Scenarios in MULINO-DSS are considered as a means to implement the effects of external initiators of the DPSIR chain and thus on the *response* to be adopted. They are the social, environmental and socio-economic settings that create changes in local driving forces, pressures and state at the catchment scale. The future scenario considered in the MULINO-DSS function allowed the decision maker to test the robustness of the decision with respect to possible future events, which could affect the reality of the catchment. A test was therefore performed with an hypothetical scenario deriving from the implementation of the Water Framework Directive. In the scenario, the construction of a new waste water treatment plant upstream of the Vallio River was considered, in order to meet the new water quality standards (Figure 7). As a consequence, the upstream loads from non agricultural sources changed and therefore the final evaluation of the alternatives presented in the current situation varied.

The evaluation of alternative scenarios is managed in the MULINO-DSS by comparison of the *decision matrices* with the decision outcomes resulting from different simulated conditions. The structure of decision matrices obtained by different scenarios is composed by the same set of the DPSIR indicators.
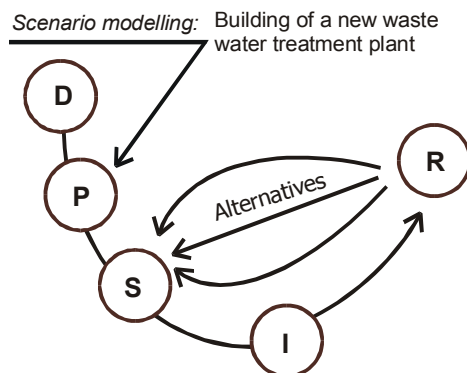

Figure 7: Scenario modelling designed for the MULINO-DSS providing a test of robustness for the final choice in case of a change of conditions, independent from the decision maker's will.

5. CONCLUSIONS

The development methodology of the MULINO-DSS, which foresees three successive software prototypes, allows the end-users involvement in the early development process. The active participation of end-users is recognised as a factor improving the acceptance of the DSS and contributing to the success of the project. The release of the first prototype of the software on the 11th month elicited creative feedback from the software users, considered in the future development progress. The most important request to emerge considered the capability for group decision making. Although the project was not designed to provide this functionality, the subsequent versions of the MULINO-DSS will include procedures supporting common understanding and modelling of the decision problem by several decision makers and stakeholders.

Since the MULINO-DSS has to meet requirements of various application contexts, the tool is being developed as a stand-alone piece of software which does not require additional commercial or public domain software except for the operating system.

The development of the MULINO-DSS is tightly coupled with the concrete needs of the future end-users, so an application driven development process has been chosen. Together with the development of the software there are five case study working groups carrying out investigations on decisional problems. The decision case studies follow different objectives and are carried out in different legislative frameworks and geographical contexts, so that only a robust tool is capable of facing these challenges.

Great attention during the first development has been paid to a suitable user interface, guiding the decision makers through the decision process. The DPSIR framework has been combined with the decision framework for this purpose. This approach aims to discover and improve awareness of the cause-effect relationships underlying the modelled decision problem.

6. ACKNOWLEDGMENTS

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