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Decision Support System for the assessment and evaluation of ecological impacts on aquatic ecosystems: objectives and framework

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Abstract: The EU Water Framework Directive (WFD), establishing stringent quality objectives for European basins in the next years, prompts for the development of new tools to evaluate and improve the ecological status over European rivers. The present paper will provide an overview of the main activities carried out in the DECIS subproject within MODELKEY, an European research project, funded by the European Commission, aimed to contribute to the assessment, understanding and prediction of the impacts of environmental toxicants on biodiversity in aquatic ecosystems. The main aim of DECIS is to develop a Decision Support System (DSS) that includes all project deliverables (i.e. exposure and effect models; key toxicants identification tool), and integrates Ecological Risk Assessment (ERA) with socio-economic valuations. In fact, DECIS specific objectives are: development of integrated risk indexes, ranking and prioritization of hot spots at basin scale, estimation of ecological risks at site-specific scale, definition of monitoring programs based on ERA results, performance of socio-economic analysis at the basin scale, technical development and application of the new DSS to three representative European case-studies (Schelde, Llobregat and Elbe). The framework of reference for the development of the DSS is presented taking primarily into consideration EU regulatory frameworks. Moreover, possible links with other existing models and DSSs for river basin management are discussed.

Keywords: Decision Support System, River Basin, Water Framework Directive, Biodiversity

1. INTRODUCTION

In Europe, the main legislative framework for the management of river basins and water quality is represented by the EU "Directive 2000/60/EC establishing a framework for Community action in the field of water policy", from now on referred to as EU Water Framework Directive or WFD.

The aim of the WFD is to establish a Community framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater and to pursue a new integrated approach to water protection, quality improvement and sustainable water use.

The Directive has established a strict temporal development, starting from the year 2004 and arriving to the year 2015, when a first full evaluation of measures has to be performed and monitored. The River Basin Management Planning Cycle, that allows to implement the WFD requirements, starts with the identification of River Basin Districts and the competent authorities. After all the assessment phases, a River Basin Management Plan, which includes characteristics of the river basin, environmental monitoring data, impacts of human activity, analysis of the economic usage of water, strategic plan for the achievement of "good status" or the Programme of Measures, has to be produced.

One of the aspects related to the river basin management is the protection of biodiversity. Particularly, the assessment of the status of biodiversity in the river basin, and the prevention, mitigation and monitoring of significant adverse environmental impact produced by economic

activities at the river basin are aspects to be assessed.
To this end, the presented MODELKEY project aims at providing an expert system that allows for the assessment of risks posed to biodiversity in river basins, according to an integrated approach that considers environmental and economic issues, and ensures stakeholders participation.

2. MODELKEY PROJECT

MODELKEY is an international research project funded by the European Commission Directorate-General within the Sixth Framework Programme, Priority Global Change and Ecosystems (Contract No 511237-GOCE).
The project started on February 2005 and has a five year duration. Therefore, this paper presents very preliminary features and description of work in progress.
The project aims to contribute to the assessment, understanding and prediction of the impact of environmental toxicants on aquatic systems at different levels of organisation (from cell to ecosystem), to the development of exposure and effect models, to the assessment and management of contaminated water and sediment, and to risk assessments on different scales.
To this respect, MODELKEY provides an original tool that can support river authorities, implementing WFD requirements or biodiversity protection objectives, in addressing some specific tasks, such as:

- identification of key toxicants present in freshwater and marine ecosystems
- spatial analysis of erosion/sedimentation processes in aquatic systems (river basins, estuaries and coastal zone)
- spatial analysis of contaminants fate and transport in aquatic systems
- spatial analysis of contaminants bioavailability and food chain transfer in aquatic systems
- integrated diagnosis of observed effects on species composition in aquatic systems
- prediction of effects of toxic exposure on single species population and the community
- analysis of toxic effects propagated through a simplified food chain
- early warning based on in vitro effects and biomarkers at a site scale
- hot spot prioritisation at basin scale based on environmental risk assessment and economic evaluation of biodiversity impairment in aquatic systems
- site-specific ecological risk assessment by risk indices in aquatic systems
- socio-economic investigation on biodiversity value.

The tools and models proposed by the MODELKEY project to address these functionalities are developed within its 6 main subprojects:

- KEYTOX aims at the development and application of tools to identify site and basin-specific key toxicants based on measurable effects in the field or in the laboratory;
- BASIN will be used to compile existing data and insert new monitoring data collected during the MODELKEY project into a database;
- EXPO will focus on the establishment of easy-to-use exposure models to predict risks of toxic pollution in river basins and adjacent coastal areas;
- EFFECT aims to develop deterministic and stochastic models to understand, diagnose and predict the effects of pollutants on populations, communities and ecosystems;
- SITE will deliver and apply experimental laboratory and field tools to analyse processes that determine exposure and effects at a site scale and will also apply innovative early warning systems such as *in vitro* assays and biomarkers;
- DECIS will develop indices and a decision support system exploiting MODELKEY results to improve the assessment of impacts on biodiversity from the environmental and economic points of view.

All subprojects are going to be applied in three different European river basins including their estuary and coastal zone: the Llobregat (Spain), a typical Mediterranean river basin; the Elbe (Czech Republic and Germany), a large central European river basin; and the Scheldt and its tributaries (France, Belgium and The Netherlands), a relatively small western European river system.

3. MODELKEY DECISION SUPPORT SYSTEM

The main output of the project will be a Decision Support System, integrating all project deliverables and providing models, databases, and case-studies examples.
A Decision Support System (DSS) is a system that helps decision makers in structuring and evaluating decisions, by providing easy-to-use and integrated tools for information elaboration and displaying (Shim et al., 2002; Watkins and McKinney, 1995; Loucks, 1995). Therefore, a DSS must provide functionalities that, depending on the specific objective of analysis, vary from information gathering and integration, learning, communication and management support.
In the case of MODELKEY DSS, the main functionalities of the DSS will concern:

- information gathering, processing and integration;
- communication;
- preliminary support to the setting up of management strategies.

In fact, the system will provide an integrated assessment of the river quality conditions. This preliminary assessment, through the definition of areas of concern (hot spots) and their prioritization, can be used by the river authorities and decision-makers to establish where to intervene promptly and actively. Besides, more specific investigations can be supported at the site-specific level.

As far as management functionalities, the DSS can support the definition of possible options by analysing the effects of different changes in input parameters (due to management choices) in the outputs variables, i.e. the calculated indices.

Due to the specific questions that the MODELKEY DSS can help to address, by including the models and tools that perform the abovementioned tasks, the MODELKEY DSS, differently from other existing tools, analyses biodiversity-related issues at basin scale in an integrated way and links them with the toxicants present in the river.

As far as the structure is concerned, a generic DSS is usually structured in 5 components: database/s (DB), analytical models (AM), graphical interface (GUI), simulation and optimization models (SOM) and spatial analysis (SA) (Jensen et al, 2002; Loucks, 1995, Simonovic, 1996; Georgakakos, 2004; Salewicz and Nakayama, 2003).

Similarly, MODELKEY DSS will include databases (DB) for river basin data (derived by BASIN and KEYTOX subprojects), analytical models (AM) aimed at integrated environmental and socio-economic assessment (derived by EXPO, EFFECT and DECIS subprojects), spatial analysis (SA) performed through GIS platform included in the system and a user-friendly and easy interface (GUI) combining Web performances with downloadable options. The simulation functionalities (SOM) will be included in the models themselves.

In addition, it is foreseen that the MODELKEY DSS will be constructed in such a way to allow the possibility of integration with other existing models and systems, in order to provide the end-users, i.e. decision-makers and stakeholders, with a collection of connected systems that can support the overall process of decision-making for river basin management. This aspect will be discussed in the description of the MODELKEY decisional framework.

4. MODELKEY DECISIONAL FRAMEWORK

For the Decision Support System that is going to be delivered by the MODELKEY project, a general decisional framework has been developed, which specifically takes into account the regulations of the WFD. In fact, as described for each of the five constituting phases, WFD requirements and actions are implemented at each stage and the framework provides the user (i.e. the competent authority) with an organized guideline that can provide support in defining specific tasks of assessment or management.

The organization of the framework is reported in Fig. 1, which shows the different composing phases, the related activities and outcomes. The framework consists of five subsequent phases:

- problem formulation,
- preliminary assessment,
- integrated assessment,
- management,
- monitoring.

This framework provides the general setting for the MODELKEY tools and results, and specifically in the Problem Formulation, Management and Monitoring phases, it addresses general WFD requirements and stages.

The more original part of the framework, which justifies MODELKEY outcomes and instruments, is instead provided by the phases of Preliminary and Integrated Assessments. Another important feature of the MODELKEY framework and the resulted DSS is that, as set by the WFD, assessment activities are performed on the environmental and the socio-economic aspects in an integrated way. Decision-makers and river authorities can consider both those aspects when carrying out their management activities.

The first phase of the framework is the <u>Problem Formulation</u> phase, which includes all the activities that, as established by the WFD, concern the identification of the basin and of the competent authority (Art. 3), the identification of the WFD specific objectives (Art. 4) and the promotion of stakeholders involvement (Art. 14), by identifying the group of all interested parties that will actively participate to the whole process.

The subsequent Assessment phases respond to the WFD which requires river characterization and classification and definition of the ecological status and quality objectives (Art. 5).

The <u>Preliminary Assessment</u> phase is the first assessment phase of the proposed framework. The main purpose of this phase is to perform a very preliminary assessment on the river basin status, based on end-user available data (i.e. physico-chemical, biological and hydromorphological). At this stage, decision-makers and stakeholders can evaluate the available raw data in order to classify the river status. If the river quality results to be acceptable, the process can be directed towards the management phase, where options to maintain the assessed good status are proposed. Otherwise, if preliminary investigations show a not acceptable or uncertain situation, then the subsequent phase (Integrated Assessment), where a more detailed assessment is performed, must be completed.

The Integrated Assessment phase provides an integrated evaluation of environmental and socio-economic characteristics of the river basin. The main outputs are integrated and site-specific indices, that supports the end-users in the characterization of river biodiversity status and impacts.

The Integrated Assessment phase can be divided into two sub-phases:

- the first *screening at basin level* allows the identification of critical areas of concern (i.e. hot spots) at the basin scale, through the evaluation of integrated (environmental and socio-economic) data;
- the second at the *site-specific level* is conducted only on selected hot-spots, where deeper environmental investigation can be performed, if deemed necessary.

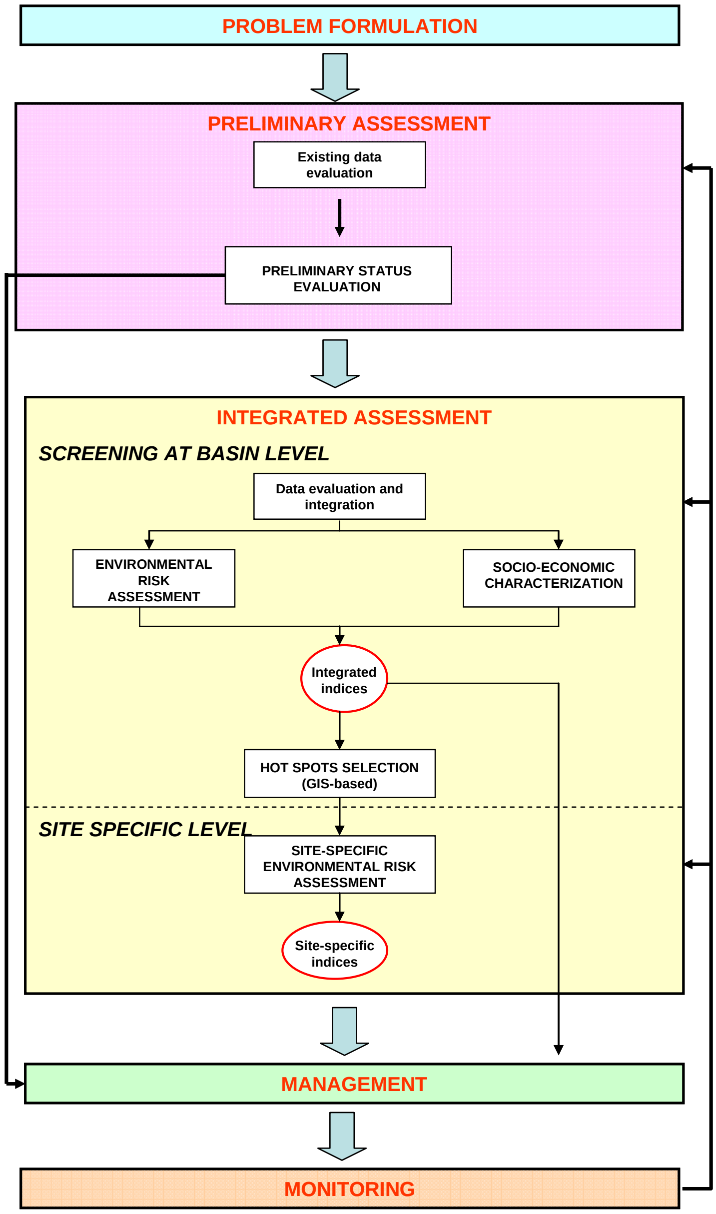

Figure 1 – MODELKEY decisional framework with the constituting phases. The preliminary and integrated assessment phases are the ones primarily covered by the MODELKEY DSS

The definition of areas of concern or hot spots is important in the light of cost-effective assessment strategies: in fact, the application of more detailed assessment activities, during the site-specific assessment, only on those areas of the river basin that actually present major problems allows river authorities to reduce overall costs and efforts.

In the screening level sub-phase, after the evaluation of existing data in order to identify missing information for the application of models, two main assessment activities must be performed, one related to the environmental issues and one related to the socio-economic evaluation.

As far as the environmental assessment, in MODELKEY the ecological risk assessment (ERA) (US-EPA, 1998) based on the Weight of Evidence (WoE) approach (Burton et al., 2002) is proposed. The related risk indices, derived by the procedure, will characterize the status of the river basin and its quality. The ecological risk assessment and the definition of risk indices would be supported by the EXPO exposure models and the EFFECT models, produced within MODELKEY project.

On the other hand, the socio-economic characterization will concern the evaluation of the main types of water uses. The related socio-economic indicators will be used to evaluate the economic importance of the alternative types of water uses. Equally, the system would provide a socio-economic indicator for the economic value of biodiversity.

The developed socio-economic indicators and the risk indices will then be evaluated together, as Integrated Indices and the results uncertainty will be provided. The integrated evaluation will allow to identify hot spots on the river basin, i.e. areas where both environmental situation and socio-economic interest can be considered more pressing. The identification and subsequent selection of hot spots will be also supported by the GIS spatial functionalities of the MODELKEY DSS, through which the link between the river and the site-specific scales can be established and resolved.

In fact, once hot spots have been identified, a detailed environmental assessment at the site-specific level can be performed. In this case, a site-specific ecological risk assessment procedure can be proposed in the system using site-specific data. The assessment leads to the calculation of site-specific indices, through which a quality status at a site-specific level can be defined.

All the information collected during the Integrated Assessment phase and identified through the basin integrated indices and site-specific indices, can compose the set of information on the river that should feed in the next phase.

In fact, the <u>Management</u> phase consists mainly in the definition of the River Basin Management Plan (RBMP). The plan, as requested directly by the WFD (Art. 13), should include characterization of the river basin, environmental monitoring data, details of the impacts of human activity, analysis of the economic usage of water and strategic plan for the achievement of "good status" or the Programme of Measures. To this respect, the data and elaborations developed within the Preliminary Assessment and the Integrated Assessment phases, supported by the use of MODELKEY DSS, constitute part of the required components of the RBMP.

The last phase is the <u>Monitoring</u>, as set by the WFD. In fact, the WFD in Annex V (paragraph 1.3) describes the design of the different kinds of monitoring programs and specifies in which cases they are requested.

By considering the presented framework and the objectives of the MODELKEY DSS, links with other existing tools and models can be discussed and possibly provided to the end-users. Nevertheless, due to the early stage of the project and particularly of the DSS development, this discussion cannot be too much detailed.

Many DSSs are already available for river basin management (Berlekamp et al, 2005; Lahmer, 2004; Fassio et al. 2005; Mysiak et al, 2005; Hirschfeld et al., 2005). Some of them, for example, accomplish functionalities of creation and evaluation of alternative management options or scenarios, such as the Havel River Basin DSS (Lahmer, 2004) that evaluates land management options and assesses the effects of man-made changes on water quantity and quality; or the Elbe-DSS (Matthies et al., 2005; Berlekamp et al, 2005; de Kok and Wind, 2003), that aims at linking management options with implemented measures in aspects such dike shifting, water quality, groyne modification, erosion reduction, by taking into account natural and economic issues at different scales.

Many systems widely rely on GIS (Geographical Information System) for visualization and elaboration purposes (de Kok et al, 2003; Moltgen and Rinke, 2004).

The developed MODELKEY DSS will be structured and proposed to be open to integration with other systems and models, when possible.

The GIS and the Web-based access can already suggest a common platform for integration of missing functionalities of MODELKEY DSS by external tools, in the light of the general framework proposed for MODELKEY (Fig. 1).

5. CONCLUSIONS

The paper has presented the MODELKEY Decision Support System in its objectives and decisional framework. The discussion has highlighted the novelty and the usefulness of the developing system in addressing decision-makers and stakeholders needs for the accomplishment of regulatory requirements. The system will be specifically instrumental in the assessment phases of the river basin management, by providing effective integrated indices at the basin as well as at the site-specific level. The use of the system will increase the cost-effectiveness of the assessment activities on the river basins and will be supportive for the subsequent definition of management options.

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