Hydrological and Ecological-Economic Simulation to Support Watershed Management: Linking SD and Geographical Information Systems

Luis Jordão, Paula Antunes, Rui Santos, Nuno Videira, Sandra Martinho

New University of Lisbon

Introduction

Water is a prerequisite for life, and a key input in virtually all human economic activity. In regions where demand for water approaches or exceeds the limits of available water supplies, competition intensifies among various interests, turning water scarcity into a potential source of problems. Scarcity often also leads to unhealthy aquatic ecosystems because of alterations in the timing, quantity and quality of freshwater flows needed to sustain their natural functions.

Especially in the most arid regions of the globe, water management is therefore becoming an important issue, calling for the development of tools that enable us to analyze how water use, allocation, and management can continue to support economic prosperity while maintaining ecological integrity. Such tools must necessarily be based on holistic approaches, linking the hydrological, ecological and economic systems, so that adequate information is generated to address decision making.

This paper presents a framework in which System Dynamics (SD) and Geographical Information Systems (GIS) are linked to support simulation and assessment of alternative land-use scenarios within the Ribeira do Torgal watershed, in southwest Portugal, taking into account its hydrological, ecological and economic impacts. The framework under development can best be seen as a collaborative working environment, allowing for a better understanding and learning of the issues at stake within the watershed, and directing decision making of stakeholders towards a systematic view of the problems associated with proposed development actions.

The Torgal Watershed

The Torgal Watershed is a 267 km^2 watershed that drains into the River Mira Estuary, one of the less disturbed coastal areas in Portugal, which is included in a Natural Park. The watershed has recently been included in the national list of sites to be protected under the EU Habitats Directive, due to its high conservation value. The latter is directly related to the existence of an endemic population of ciprinidae, as well as of a stable community of otters, among other protected fauna and flora.

The abandoning of cereal cultivation, in order to make place for intensive forestry with *Eucalpyptus globulus*, a major input for the paper pulp industry, has been an important driving force for land use changes in the surrounding since the 50´s. Due to its higher short-term profitability, eucalyptus has been preferred to the traditional multiple use "montado" system, based on cork oak forestry. This has aroused criticism due to the fact that eucalyptus plantation slower the water table, reduce biodiversity, cause soil erosion, have a low aesthetic value and provide fewer products for local populations. On the contrary, the traditional montado system is believed to be a sustainable land-use and make a substantial contribution to maintaining environmental stability in the adverse soil and climatic conditions of the region (Almeida & Riekerk, 1990).

Forestry with eucalyptus has also reached the Torgal watershed. However, the number of land-use changes in the area has been smaller, mainly due to its poor soils and low accessibility, that diminished its attractiveness for forestation. Even so, eucalyptus land cover has increased along the years, and the fear exists that in the near future it may become a threat to water availability, as well as to the nature conservation objectives currently under discussion. Associated with these problems, the fact that not all costs and benefits associated with forestry actions are being taken into account, has called for the development of integrated management support tools. These should allow a better understanding and learning of the issues at stake, directing decision making of stakeholders towards a holistic view of the problems associated with land-use changes, and their respective hydrologic, ecological and economic impacts at the watershed level.

The Decision Support Framework

As stressed by Naiman (1996), there is no general methodology for achieving a holistic water management perspective, but, if one was to be formulated, it would require guiding principles related to cooperation, balance, fairness, integration, trust, responsibility, communication, and adaptability. Being aware of the abilities of freshwater systems to respond to human generated pressures, their limitations in adapting such challenges, and developing modelling environments that link social, economic and environmental considerations are fundamental to an understanding of proposed actions.

Also, few river research and management questions can be answered without considering landscape or ecosystem attributes and dynamics. Natural resource management questions have to be addressed in a landscape context, owing to the interactive nature of ecological processes that provide ecosystem services and goods. River ecosystems encompass ecological, social, and economic processes that interconnect organisms, including humans, with their environment within a defined catchment landscape and over some specific time period (Stanford, 1996). Managing for biodiversity, water quality, and disturbance within such ecosystems demands a landscape perspective. One must deal with the entire landscape and begin to anticipate how activities in one area might affect the physical and biotic properties of adjoining areas. Because landscapes are both complex and dynamic, managers will need tools such as spatial models to aid them in their decision-making (Turner et al., 1995).

Considering the above exposed, a framework that links SD modelling, GIS, and the involvement of relevant stakeholders in the area is currently under implementation. This will constitute a basis for the simulation of alternative land-use scenarios, and analysis of their respective impacts in the hydrologic, ecological and economic systems within the watershed. To address these, a close link is established between a SD model built in *Powersim*, georeferenced information stored in a raster based GIS, *Idrisi for Windows*, and the user interface developed in *Visual Basic for Applications* within *Excel*.

As presented in figure 1, spatial heterogeneity's associated with the hydrologic and ecological systems are taken into account in simulation by an array module of the SD model that represents the biophysical system, which makes use of georeferenced information stored in the GIS. Exchange of information is performed by the user interface through the *NovaGIS OLE Object* (Gonçalves,1997), that allows access to information stored in Idrisi files within a *Windows* environment. The SD model comprises also a scalar module representing under an aggregate form the socio-economic system within the watershed. In this module, a set of indicators describing the state of the system is also considered.

The user interface is the main control for the simulation process, allowing to choose which scenario to run, and to observe results both in terms of maps (Idrisi files) and graphs representing the evolution of key variables.

Stakeholder participation plays an important role in the framework, both in the identification of the variables and in relationships to be included in the SD model, as well as in the spatial definition of the alternative land use scenarios to be assessed. In this context, the underlying idea is to use the GIS in order to generate each stakeholders "plan" for the watershed, as well as a consensus plan that maximizes each stakeholders interests, in a similar methodology to that described by Cocks & Ive (1996).

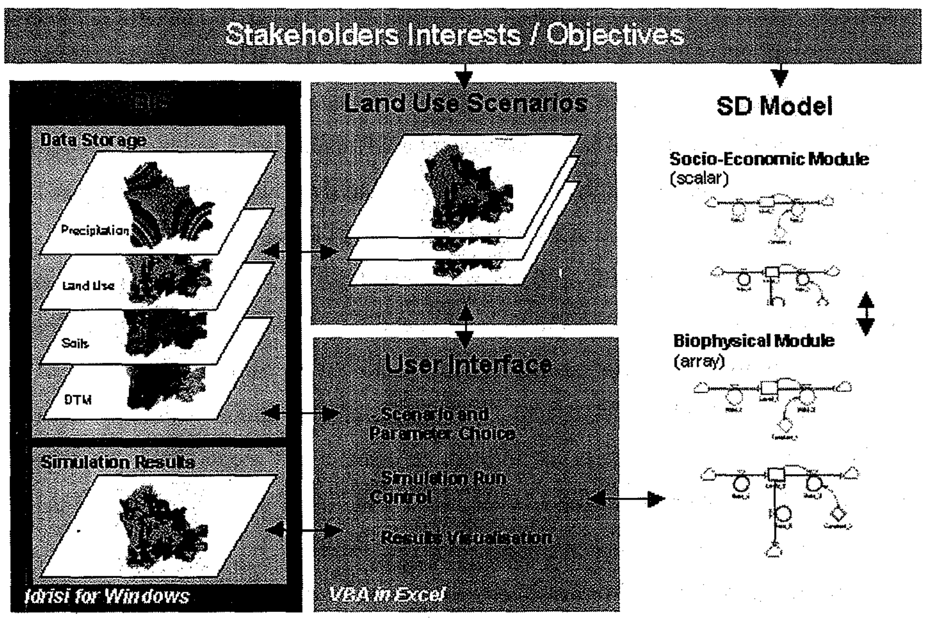

Figure 1 –Diagram of the Torgal Watershed Modelling Environment.

An updated description of the current state of development of the presented framework is found in the virtual proceedings, where more detailed information regarding the components presented in figure 1 and their links are also given.

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