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Paula A. Silva

Paula Antunes

Daniel Borrego

Jojo Rocha

Nuno Videira

See next page for additional authors

Presenter/Author Information
Paula A. Silva, Paula Antunes, Daniel Borrego, Jojo Rocha, Nuno Videira, and Rui Santos

A Dynamic Model for Sustainable River Basin Management

Paula Antão da Silva[a]; Paula Antunes[a]; Daniel Borrego[b]; João Rocha[c]; Nuno Videira[a]; Rui Santos[a]

[a] *New University of Lisbon, Monte de Caparica, Portugal*

[b] *Institute of Marine Research, Coimbra, Portugal*

[c] *National Laboratory of Civil Engineering, Lisbon, Portugal*

Abstract: The European Water Framework Directive (WFD) introduced an integrated perspective in water resources management, based on an approach where the river basin is the management unit and the active involvement of all affected parties by its river basin management plan is clearly encouraged. The integrated perspective is required to develop sustainable resource management strategies adapted to the institutional, cultural and legal tradition in a region, taking into account the human dimension of the problem. A dynamic model capable of integrating quantitative and qualitative data and relationships between technical, ecological, economic and social driving forces, typical of water resources management problems, is being developed, supported by a Portuguese research project. The framework methodology includes the participation of main stakeholders belonging to the case study selected, the Arade river basin (AradeRB), in the southwest of Portugal, in a series of workshops. A combination of data-based and participatory-based systems analysis is pursued within the perspective of disciplinary integration of physical, ecological and socio-economic scales of water management, towards the formulation of sustainable governance scenarios for a river basin, in particular to AradeRB. The model is being built considering the four main economic sectors in the AradeRB: tourism, agriculture, forest and pig breeding. After the establishment of the cause-effect relationships between these sub-sectors (and sub-models) the conceptual model was implemented in STELLA, a type of software adequate for dynamic simulation. The modeller is now linking these sub-models one to the other three and all to the hydrodynamic and the demographic sub-models. Besides, exploratory scenarios accounting for different socio-economic development strategies are being built for simulation and evaluation in terms of their ecological, economic and social impacts to water demand and supply within the system of AradeRB. In this phase, the time horizon is the year 2025. Afterwards, trade-offs between AradeRB water uses will be considered, in order to guarantee the availability of water to the different uses with respect to the legal degree of quality. The first workshop with the stakeholders took place on April 2005, where causal relationships were discussed and refined, by means of a SWOT analysis. On mid-2006 a second workshop is going to take place, where a set of plausible scenarios for the AradeRB are expected to be suggested, discussed and selected. A final workshop will occur in the last trimester of 2006. Between the workshops, the model (called Sushid) is improved and simulated. This model may be a valuable tool for the establishment of river basin management plans in Portugal, which accordingly to the European WFD have to be approved by 2009.

Keywords: River basin management; Sustainability; Dynamic model

1. INTRODUCTION

In contrast to traditional water resources management, focused on a specific and single domain of water use (water supply, pollution control, irrigation, power generation, wastewater treatment, etc.), a sustainable vision of water use insures the water resources protection across generations, reflecting a change to new paradigms that include human scale factors as part of the system complexity.

Since the late nineties a new approach, defending a strategic and integrated sustainable use of the water resources and adapted to institutional, cultural and legal traditions of each European river basin is being established among the Member States of the European Union. It gathers all the sectors mentioned above, into a unified framework in which every domain has a specific importance, depending on the priorities in each river basin. Besides, all the stakeholders in the river basin are invited to participate, in a process where communication is the most important element, interconnecting different sectors and their specific actions [Teodosiu et al., 2003]. This framework had been translated to the European Water Framework Directive, approved in 2000 [EC, 2000]. It creates the context to implement a water policy regarding the protection and the sustainable use of European water bodies (surface and groundwater) in order to attain a "good ecological status". The river basin – the natural geographical and hydrological unit, seldom coincident to administrative or political boundaries – may be the best approach to accomplish that task.

This unified legal frame creates the scientific and technological base for the implementation of integrated water resources management policies, according to the principles of sustainable development – a water system may be considered sustainable if it satisfies long term and short term demands of water, paying respect to their ecological function.

One of the instruments of the European Water Directive water policy is the *development of management plans for each river basin district* that ought to be published by December 2009, and should be reviewed and updated every six years afterwards.

Another instrument is *public participation* referred in article 14 of the Directive: "Member States shall encourage the active involvement of all interested parties in the implementation of this Directive, in particular in the production, review and updating of the river basin management plans." But WFD leaves to each Member State the responsibility of defining where and when public participation is better adapted to local, regional and national circumstances but it should be kept transparent in all phases either to direct and indirect agents (the stakeholders) or to the general public; on the other hand, encourages the involvement of the agents from the beginning of the planning process in order to make the process interactive and facilitate final agreements between multiple values and objectives, often in conflict. Then, besides the necessity of ecological and economic objectives to be attained, the WFD recognizes the growing need of participation of all concerned parties in the decision processes

In fact, "adaptive water management", built on the concept that management is a collective learning process in complex adaptive systems such as a river basin, is improving. Due to the interdependency of natural, social and technical aspects this transition has to be based in a collective learning. Water resources management faces a number of uncertainties from economic constrains to possible climate change, each one with their own rate of change and boundary conditions, increasing the need to implement integrated water resources management strategies clearly different from the traditional ones [Pahl-Wostl, 2004].

2. OBJECTIVES

The objective of this work is the development of a dynamic model at the river basin (geographic) level capable of expressing ecological, economic and social causal relationships (qualitative and quantitative when possible) between availability and uses of water and their societal causes.

Knowing these relationships the construction of plausible scenarios will be feasible, accordingly to different socio-economical strategies. These management scenarios and their implications upon demand and supply of water will allow the evaluation of ecological, economic and social impacts of each scenario.

3. METHODOLOGY

3.1 Framing

Although system analysis has been successful in developing models of complex systems, few of these models are actually used for policy making. To improve this situation, one should aim to develop an interactive approach between the analyst or modeller – having a comprehensive idea of the whole system - and the stakeholders, at several steps of the process.

Policies implemented to address water resources problems frequently address only their most visible causes. However, the root causes, e.g. the diverse social, cultural, institutional, economic, technological and political factors that drive them, must also be addressed. The need to reconcile the demand for water (of good quality and adequately distributed in space and time), with the integrity of aquatic ecosystems, has become an increasingly important issue, namely in the context of the European WFD. As water availability is limited this situation generates conflicts, leading to a mismanagement of water resources, requiring the development of new approaches.

This work suggests a new approach for river basin management, combining the development of a dynamic simulation model (representing the causal factors underlying water problems) and plausible scenario building exercises. The underlying methodologies and methods (usually applied in the context of global water resources problems) are briefly described in the following sections. To test this approach a Portuguese case study had been chosen – the Arade river basin (AradeRB) located in the southwest coast of Portugal (in the Algarve region).

3.2 Causal Relationships within the Arade River Basin. SWOT Analysis

The application of causal chain analysis has been suggested for river basin management [GIWA, 2002]. Causal chain analysis traces the cause-effect pathways, associated with each significant water resources problem, from the socio-economic and environmental impacts back to its root causes, in order to target them by appropriate policy measures. Nowadays, the most widely accepted framework to help with this task is the "Driving forces-Pressure-State-Impact-Response model" (DPSIR), an extension of the PSR (Pressure-State-Response) model developed by Anthony Friend in the 1970s.

An environmental management process may be described as a feedback loop controlling a cycle consisting of five stages that when applied to the river basin management are described as presented in Figure 1, for instance.

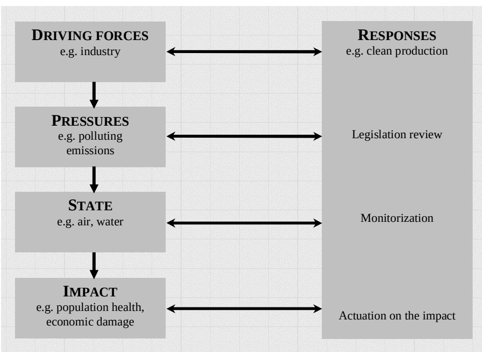

Figure 1. The DPSIR framework applied to water resources management [adapted from EEA, 1999].

SWOT is an acronym of "Strengths – Weaknesses – Opportunities – Threats", standing for an analysis procedure commonly used in the development of marketing plans and decision support. It accomplishes this by assessing an organization's strengths and weaknesses (what can and cannot be done) in addition to opportunities and threats (potential favourable and unfavourable external conditions). SWOT analysis, being simple to implement, is an important step in planning, providing direction and serving as a basis for development scenarios and may clearly be used on river basin management providing information that is helpful in matching the system resources and its capabilities to the environment in which it operates (socio-economical and environmental actions). Based on the expertise of those involved in the planning process, SWOT analysis is essentially qualitative. The necessity to quantify the hierarch importance of factors leads to the association with other methodologies for the analysis of complex decision problems like AHP (Analytic Hierarchy Process). SWOT provides the basic frame of analyses and attributes weights to its factors and AHP performs the quantitative analysis the output being quantified priorities for the SWOT factors (Kurttila et al., 2000).

3.3 Workshops

Figure 2 shows schematically the way stakeholders of Arade river basin are involved in this work and which results to expect.

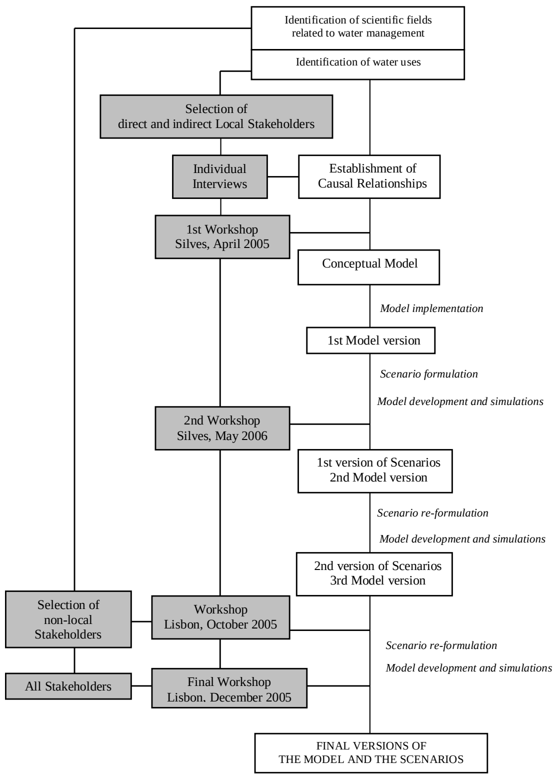

Figure 2. Approach to stakeholders and results mapping [adapted from Silva et.al, 2005].

The 1st workshop took place on April, 2005, in Silves, a town belonging to the AradeRB. In the meeting a SWOT exercise was fulfilled with the participation of the stakeholders and the research team as the facilitator part [Antunes et al., 2005].

Once the main economical activities within the AradeRB were identified - agriculture (in particular, irrigation), pig breeding, tourism and forest exploration - the stakeholders first established the factors for each S, W, O, and T groups. Then they had to classify the degree of importance between each pair of factors within each group assembling a SWOT matrix. Table 1 and Table 2 present the results for the forest sector.

Table 1. SWOT factors identification for the forest sector of Arade river basin [Silva et al., 2005]

Internal		External	
Strengths	Weaknesses	Opportunities	Threats
Large area	Lack of planning	Area increase	Fires
Cork quality	Lack of good practice	Better trees	Cork tree diseases
Wood quality	Pasturing	Complementarity with farming systems	Depopulation
Landscape	Hill slope conflict	Avoid depopulation	Delay on regional forest planning
Aptitude		Increase industrialization	Lack of forest cleaning

Table 2. SWOT matrix for the Threats on Forest sector of Arade river basin [Silva et al., 2005]

	T1	T2	T3	T4	T5
T1					
T2	very strong				
T3	equal	weak			
T4	strong	strong	very strong		
T5	strong	very strong	very strong	strong	

On the 2nd workshop, expected to the end of May, 2006, a tentative exercise of scenario-making is going to involve, again, the same stakeholders of the first meeting. They will be invited to construct "pathway scenarios" to help them, how they can get from the present condition to a desired condition.

Four scenario methods could be considered for the purpose of scenario-planning for water resources management: vision, projection, pathway or alternative scenarios. In the present approach we may elect the method of *pathway scenarios* as the most appropriate. In fact, pathway scenarios combine elements of vision and projection scenarios; the key difference from the other methods is that the learning focuses on problem-solving and creating strategies for dealing with the constraints and opportunities for achieving a future goal, rather than on trying to internalize the possibility of a particular future [Wollenberg et al., 2000].

3.4 Water Management Scenarios

Scenario-based planning is one approach to developing a long view. Although scenario-based planning dates back more than 50 yr, it is only in recent years that it has been applied to natural resource issues. This type of planning is an important part of the "Millennium Ecosystem Assessment" of the capacity of the world's ecosystems to support social and economic development [Gunderson and Folke, 2003].

A scenario can be defined as an internally consistent (plausible) pathway (new values for state variables, flows and information) into the system's future within the context of different causal frameworks. Scenarios are not predictions but projections of the future state of the society and the environment based on specific assumptions about key determinants such as economic and social development, technological change or public policies. The development of scenarios allows a better understanding of how systems behave, evolve and interact.

The story-and-simulation (SAS) approach to scenario development proposed is a promising tool in the context of river basin management. In this approach a storyline describes in story-form how relevant events, key driving forces and step-wise changes unfold in the future, while model calculations complement it by presenting numerical estimates for representative variables. The process combines factual analysis derived from observation and modelling with the knowledge and subjective perceptions from stakeholders. The stakeholder team helps with the verbal description of the scenarios (the story) while the modelling team perform their simulations. The following discussion of the quantitative results among the whole group and the subsequent model computation help to review and maintain the consistency of the storylines. This combination of modelling and participatory approaches provides long term guidance for short term sustainable decision making relevant for the establishment of water policies to be applied to river basin management [Alcamo, 2001].

4. THE DYNAMIC MODEL

4.1 Model Description

The overall assumptions for the development of the dynamic model are (i) the geographical unit is the river basin area, (ii) the natural resource in focus is surface freshwater and (iii) estuarine water and adjacent coastal water are not to be considered.

In Figure 3, the conceptual model for AradeRB is shown.

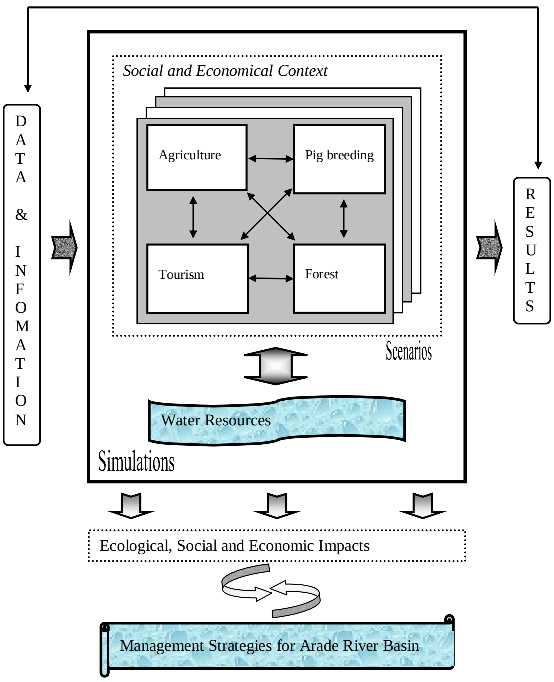

Figure 3. The conceptual dynamic model for Arade river basin.

The main components (sub-models) of the dynamic model are (1); domestic abstraction of water, including the hostelling share from tourism; (2) water for agriculture, particularly farming consumption on irrigation (3) water use for pig breeding; and (4) water consumption from the forest sector. Beyond the scene, are the demographic and the hydrodynamic "layers".

In principle, the model will be able to quantify/qualify the impacts on water quantity and quality and on the "ecological function" of the river basin. Finally, a management interface will integrate all the actions within the AradeRB and be ready to evaluate the ecological, social and economic costs for each and water use(s), within different scenarios of exploitation. This interface is under construction.

4.2 Foreseen Results

Today, the model (with the acronym "SusHid", for Hydric Sustainability, in Portuguese) only simulates the behaviour of the system with historical data, without scenarios. It will soon simulate different scenarios, accounting for the suggestions and discussion emerged from the meeting of scenario-planning exercise with the stakeholders participating in the 2nd workshop.

5. CONCLUSIONS

A dynamic model capable of integrating quantitative and qualitative data and relationships between technical, ecological, economic and social driving forces, typical of water resources management problems, is being developed, supported by a Portuguese research project. The framework methodology includes the participation of main stakeholders belonging to the case study selected, the Arade river basin, in the southwest of Portugal (Algarve region), in a series of workshops.

The model (named SusHid) is being built considering the four main economic sectors in the Arade river basin: agriculture, pig breeding, tourism and forest exploration. After the establishment of the cause-effect relationships between these sub-sectors the conceptual model was implemented in STELLA (cf. www.iseesystems.com), a type of software adequate for dynamic simulation. The modeller is now linking these sub-models one to the other three and all to the hydrodynamic and the demographic sub-models. In this phase, the time horizon for simulation is the year 2025, only based on historical data.

Exploratory scenarios accounting for different socio-economic development strategies are being built for simulation and evaluation in terms of their ecological, economic and social impacts to water demand and supply within the system of Arade river basin. This exercise is the main output of the 2nd workshop, which is going to take place with the participation of the stakeholders of AradeRB, whom had also participated in the SWOT analysis exercise (in the 1st workshop). These exercises are accounted with the facilitation task of the research team.

The next step is to trade-off water uses for the Arade river basin, in order to guarantee the availability of water to the different uses with respect to the legal degree of quality.

This tool may be a valuable contribution to the definition of integrated strategic management for Portugal concerning the development of river basin management plans (as stated in article 13 of the WFD) and in supporting pro-active participation of the relevant agents before approval of the plan (as underlined in article 14 of the WFD).

6. ACKNOWLEDGEMENTS

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