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System Dynamics Modelling (SDM) is a methodology for studying and managing complex feedback systems, typically used when formal analytical models do not exist, but system simulation can be developed by linking a number of feedback mechanisms. Forrester (1961) introduced system thinking and SDM in the early 60's as a modelling and simulation methodology for long-term decision-making in dynamic industrial management problems. Since then, SDM has been applied to various business policy and strategy problems (Barlas 2002). Consequently it has proven to be very useful for the simulation and study of complex environmental (Ford 1999, Mulligan and Wainwright 2004) and water systems (Simonovic 2003) in an integrated way.

Constructing, examining, and modifying System Dynamics Models (SDM) follows an iterative approach. Starting from conceptual qualitative models, simple quantitative models with few feedback loops and little detail are built, so as to allow the construction of an initial working numerical simulation model (Ford 1999). The working model can then be modified and improved as necessary to show the desired level of detail and complexity.

AquaStress-Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments (AquaStress 2005) is an EC FP6 IP project (2005-2009), comprising 35 international partners and 8 case studies, which differ considerably both in technical and spatial/societal terms. Some of the case studies involve agriculture/irrigation/water allocation issues, while others focus on urban/industrial water quantity/quality problems, the locations ranging from Northern Europe to Northern Africa. Most case studies involve re-cycling/re-use and/or re-allocation of water, whose water quality in turn varies over time and space. Additional complications arise by occasionally incomplete data and by the need of introducing interactive participatory processes at every stage, leading to application-driven investigations. Each case study is considered to be a highly complex water system, where water management options technically available (e.g. water re-use, groundwater management, desalination etc), links, interactions and consequences, all aiming at water stress mitigation, are interlinked and hard to simulate separately, i.e. without taking into account their internal connections.

Therefore in order to establish a common ground as well as a common approach from the engineering point of view, conceptual modelling and SDM have been applied. Consequently a SDM software tool has been included in the AquaStress "Integrated

Solutions Support System" (i3S), a software environment that brings together data, information, knowledge and tools being used and developed within the AquaStress project by different partners and stakeholders (AquaStress 2006a).

The purpose of this paper is to describe the SDM tool selected for the project, the participatory process for its application, as well as a characteristic prototype case study.

Mathematically all (or most) existing SDM visual environments are similar (AquaStress 2005). Here SIMILE (Muetzelfeldt & Massheder 2003, www.simulistics.com) has been selected as the primary software platform for implementing the quantitative (numerical) model for the case studies, for two reasons: (a) it efficiently supports breaking the model into sub-models, thus facilitating the development process of very complex systems, and (b) it can automatically produce model documentation (code) in C++, thus making the model potentially re-usable for further specialized applications, if necessary. Additionally the VENSIM (Simonovic 2003, www.vensim.com) graphical environment has been used for developing the qualitative conceptual/causal loop diagram of the system.

Within AquaStress a continuous interactive process, requiring mutual interdisciplinary communication and understanding at all stages is applied, between two different groups of participants. The first group consists of interdisciplinary "experts", who define, describe and suggest various "technical options" to be potentially applied for solving a problem (i.e. mitigating water stress) in specific case studies. The second group comprises local "stakeholders", who present the case study to the experts, together with initial suggestions for solving the problem, listen to further suggestions, react to them by accepting/ rejecting/modifying them and finally implement the "solution". Consequently SDM has been applied, according to the following step-by-step procedure (Vamvakeridou-Lyroudia et al 2007):

1. Initially all (project specific) technically available water management options available for improving conditions, are defined and formally conceptualized in SDM terms (i.e. as stocks, flows and converters) by the "experts". These generic conceptual diagrams are considered to be the "building blocks" for each water system within the project.
2. Problem identification at system level for each case study follows, together with the description of a dynamic hypothesis explaining the cause of the problem. This step requires interactive cooperation between "experts" and "stakeholders".
3. The conceptual (qualitative) model (diagram for each system/case study is built, by combining and linking several technical options, again through an interactive procedure (AquaStress 2006b).
4. Consequently case study specific initial quantitative models (including numerical data and parameters), are being developed, in SDM visual environment/mode by the "experts", revised and approved by the stakeholders.
5. SDM models are updated and improved interactively, i.e. by presenting and discussing intermediate models to the "stakeholders", gradually modifying and improving them through discussion and consent.
6. The models are tested and evaluated by the "stakeholders", to make certain that they represent the behaviour seen in the real world (model evaluation). If necessary further improvements are carried out (return to Step 5).
7. The final SDM models are being used for generating alternative scenarios, exploring factors, policies and impacts, aiming at supporting the decision making process.
8. "Solutions" are selected and implemented by the stakeholders, while at the end of the project, the SDM models remain with the stakeholders for further use.

The prototype for the application of SDM within AquaStress, presented in this paper, is the case study of the Kremikovtzi water system. The Kremikovtzi plant, near Sofia, Bulgaria, initially constructed in 1963, was designed to support a complete metallurgical cycle, contributing nowadays to about 2% of the Gross Domestic Product of Bulgaria and over 10% of the Bulgarian exports to the EU. In terms of water use the plant is one of the biggest water consumers in the country, its average yearly water consumption being roughly equivalent to a city of 600000 inhabitants (Dimova et al 2007, Vamvakeridou-Lyroudia et al 2007).

The Kremikovtzi industrial water supply system is extremely complex and consists of both fresh water and reused water sources. The fact that some of the system fresh water sources are also used by urban and agricultural water users in the Sofia region, leads to regulations for priorities and upper limits to water consumption for industrial use, as well as water stress situations arising in times of drought. The purpose of the SDM model is to improve water management within the system, by (a) studying the effects of increased water re-cycling rates (b) estimating the effects of drought, by simulating "normal", "dry" and "very dry" years. The SDM application has now been completed (Steps 1-6), 23 different operational scenarios have been evaluated, while the final selection (Step 8 of the procedure) as well as the formal evaluation of the SDM tool by the stakeholders, took place in May 2008, while full documentation, is available for downloading (Vamvakeridou-Lyroudia and Savic 2008).

Within AquaStress SDM has been designed as a stand alone tool. Communication with other tools exists, as follows: The Questionnaire tool can provide an initial approach to the case study, by reflecting the stakeholders' views on critical local issues (Steps 1 and 2 in the procedure). In a similar way the Knowledge Base provides useful information about technical options available (Step 3), while numerical data for the quantitative model can be retrieved from the Data base (Step 4). However in the prototype application this has not taken place, because inevitably, the development of each i3S tool took place in parallel during the project. Consequently, the SDM prototype was for instance between Steps 4 and 5, before the questionnaire was available as a tool.

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