The Riacho Fundo water basin: a case study for qualitative modelling sustainable development

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Abstract

This paper presents a working plan for modelling relevant aspects of sustainability issues in the Riacho Fundo water basin, as a case study for the NaturNet - Redime project. According to stakeholders, the most important problems in the basin are uncontrolled land occupation, deforestation, unsustainable practices in agriculture and industry, governance and low level of public participation. Following a framework for building qualitative models developed for the project, a concept map was created and became the basis for a structural model of the Riacho Fundo system. From that we developed three causal models to express the system behaviour and planned the implementation of scenarios and model fragments. The approach is illustrated by designing a model about functional springs. Finally we present our conclusions and discuss ongoing work.

Introduction

As a concept, sustainable development expresses complex interactions between biological, chemical, physical, social, economic and cultural factors and desirable states of dynamic equilibrium at levels in which current use of resources allows future uses. The Riacho Fundo water basin, located nearby Brasilia, the Brazilian capital, provides an interesting case study for the development of qualitative models about sustainability, in the context of natural and rural areas being transformed into urban areas.

According to local stakeholders, the most important problems in the basin result from uncontrolled land occupation. Building up new urban areas lead to deforestation and loss of natural ecosystems; once installed, these urban areas bring about problems related to sewage and garbage disposal, and to economic activities. Following the Brazilian legislation, a Water Basin Committee (WBC) is being organized in the Paranoá Lake basin, with a sub-committee in the Riacho Fundo basin, aiming to implement sustainable water management practices (Salles, 2001). Members of the Committee and other stakeholders need support for understanding environmental systems and problems that may affect sustainability in the basin, and there are no good quality educational tools and simulation models to address such complex problems.

Qualitative Reasoning (Weld and de Kleer, 1990) has proven to be a useful approach for modelling sustainability issues. Eisenack and Petschel-Held (2002) and Eisenack (2003) describe qualitative models used for understanding the interactions between nature and society to support a global sustainable development. Salles *et al*. (2005) present a set of qualitative models that include environmental indicators selected for monitoring the Millenium Development Goal related to environmental sustainability in Brazil and the effects of the destruction of riparian forests in the Riacho Fundo were studied by Anjos (2005).

Recently, the Naturnet-Redime project (www.naturnet.org) has adopted a QR approach for a modelling effort addressing a broad range of sustainable development related problems. The models aim at supporting stakeholders to understand the systems they have to decide upon and the consequences of the decisions they make. Case studies in five countries involving six degraded river basins are being undertaken. A framework for structuring the modelling process (Bredeweg *et al*., 2006b) is being used (a) to organize the representation of contents; (b) to support the development of a conceptual understanding of the systems structure and behaviour; and (c) for further evaluation of intermediate and final results of the modelling effort. In fact, this paper presents background knowledge for the Brazilian case study in a way that can easily be compared to other case studies at the same stage, such as the ones in Bulgaria (Uzunov *et al*., 2006) and in Romania (Cioaca *et al*., 2006).

Initially, in section 2, an overview of the most important sustainability problems of Riacho Fundo basin is given. In section 3, a brief summary of QR and the adopted approach are presented. The structural model relating entities and configurations is presented in section 4. From that we discuss the most relevant processes that shape the Riacho Fundo system global behaviour. The causal model for expressing the maintenance of functional springs is presented in section 5. In this section we explore also the expected behaviour for this model, defining quantities that could better represent relevant properties of the entities. The implementation of model fragments is discussed in section 6. Finally we discuss ongoing work and present our conclusions.

The Riacho Fundo basin

The Riacho Fundo water basin is located in the middle of the Cerrado, the second largest Brazilian biome, where there are two well distinct seasons, a dry and colder season from May to September, and a rainy and warmer season, from October to April. Riacho Fundo is a stream with approximately 15 km of extension, and its drainage area is 225,48 km² (Fonseca, 2001). This river basin has been one of the most disturbed areas since the 1950's, when the new capital was built. Nearly all tributaries of Riacho Fundo present nowadays a high degree of eutrophycation due to the discharge of sewage and garbage (Silva, 2000), and erosion is found all over the basin. However, the basin holds 14 legally protected areas, a decisive factor for conservation of the remaining natural vegetation cover and, consequently, of important natural resources such as biodiversity, for example.

During meetings held for the WBC creation, stakeholders identified what they consider to be the most relevant problems in that basin: (1) uncontrolled land occupation; (2) problems with basic sanitation; (3) unsustainable management practices by farmers and by the industrial sector; (4) incomplete, inadequate or absence of governmental actions; (5) weak participation of the community in the environmental management of the basin.

The approach selected for the Riacho Fundo modelling effort is described in the next section.

A Qualitative Reasoning modelling approach

The process – centred approach (Forbus, 1984) was selected for this modelling effort. Two types of modelling primitives are of great interest: *direct influences*, used to describe how state variables change at a certain rate due to processes, and *qualitative proportionalities*, monotonic functions that propagate the effects of processes. The former are represented by I+ and I–, and implement operations for adding and subtracting the value of the rate from the derivative of the state variable, respectively. The latter, represented by P+ and P– , implement relations that cause the influenced quantity to change in the same direction as the influencing quantity, or in the opposite direction, respectively.

The models are being built in Garp3 (Bredeweg *et al.* 2006a), a qualitative reasoning engine that provides a an integrated environment with graphical interface for model building, running simulations and visualizing the simulation results. We adopted a compositional modelling approach (Falkenhainer and Forbus, 1991) and used a vocabulary that can be understood by the 'folk on the street', a crucial point to achieve the goals defined for the NaturNet – Redime project. Details of the model are presented in the following section.

A model for the Riacho Fundo case study

Based on interviews with stakeholders and in a concept map built for organizing knowledge to be addressed in the model about the Riacho Fundo, we developed the structural model consisting of entities (represented in square boxes) and configurations shown in Figure 1:

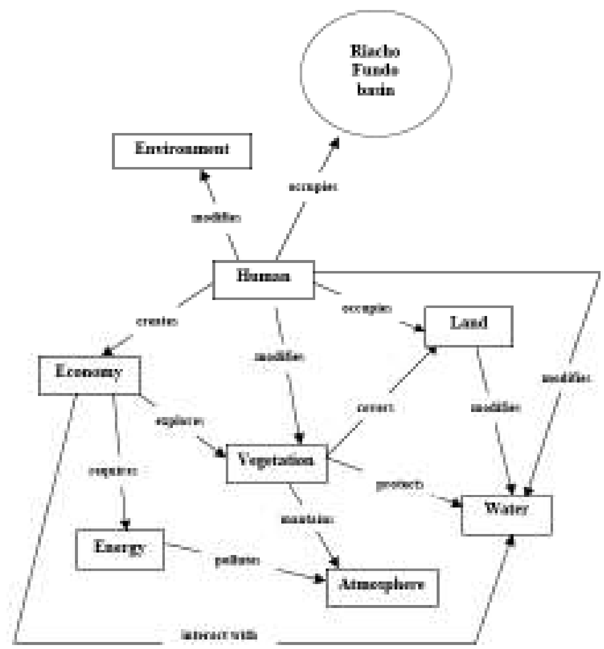

Figure 1. Structural model for the Riacho Fundo case study.

The most important entities are *Human*, *Environment*, *Economy*, *Land*, *Energy*, *Vegetation*, and *Water*. Entity *Human* represents active human actors in the basin, and has subtypes to represent farmers, industrials and ecologists. *Environment* includes a number of environmental factors such as soil, water, biological resources, climate and pollution. *Economy* represents activities such as agriculture, industry and services. *Energy* includes both renewable and non renewable sources of energy. *Land* is related to land uses. *Vegetation* is used to introduce the most important biological resources. *Water* refers to underground water, streams and springs.

The global behaviour of the Riacho Fundo system is determined by a number of physical, chemical, biological, economic and social processes. Their effects propagate to other parts of the system, resulting in the main problems identified by the stakeholders. From these observations, three causal models were built, aiming at representing (a) urban aspects, such as soil impermeabilization, the drainage system and the impact of torrents; (b) soil related aspects, such as erosion and fertility loss; and (c) the maintenance of functional springs, including aspects of the water cycle. In this paper we present, for illustration, only the third causal model.

Springs causal model and expected behaviour

Many springs and small streams in the Riacho Fundo basin have already disappeared. However, nowadays springs and the remaining areas with vegetation cover are legally protected conservation areas.

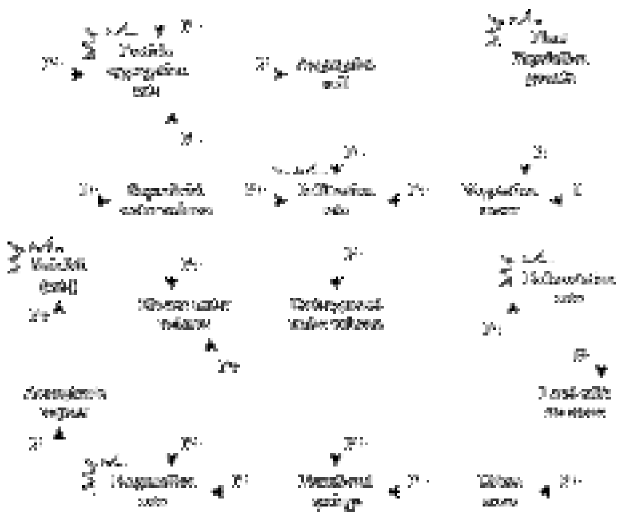

Figure 2. Fuctional springs causal model.

According to the causal model shown in Figure 2, the aggregation process of soil particles is influenced by vegetation cover, because the root system reduces soil compactation. In opposition to that, in urban areas vehicles, heavy artifacts and asphalt cause the soil to become compact and water proof. Deforestation reduces the land covered with vegetation and increases the area without vegetation cover at a certain rate. There is a feedback loop involving the creation of new urban areas, which is related to the number of functional springs. The latter quantity is also influenced by underground water volume. Changes in functional springs influence stream water volume. In this model, superficial and spring water are related to the evaporation process, that contributes to the rainfall. The qualitative states that quantities may assume are captured in their quantity spaces (QS). Rates have QS = {*zero*, *plus*} or {*minus*, *zero*, *plus*}. Quantities related to urban area, vegetation cover and water volume (underground, surface, spring and atmospheric vapour) have QS = {*zero*, *small*, *medium*, *large*}; particle aggregation state has QS = {*free*, *loose*, *medium*, *moderate*, *compacted*}.

Important external influences that may change the system in some way can be included in the causal model presented here. Agents may be used for this purpose (Bredeweg *et al*., 2006a). For example, farmers modify the particle aggregation rate positively or negatively (because they can plough the soil or make it more compact by using heavy machines); and governance may implement laws to control deforestation.

The model can be used to simulate two typical situations: (a) favourable scenarios, in which deforestation is smaller than plant population growth; in this case, water resources are preserved so that the volume of water in functional springs increases, and some springs may reappear; (b) unfavourable situations caused by human occupation, that lead to increasing soil particles aggregation, decreasing infiltration, and thus reducing the number of functional springs.

Implementation of model fragments

We anticipate here some model fragments (MF) required for implementing the ideas described above. Three types of MF are considered: process, static and agent fragments (Bredeweg *et al*., 2006a). For each MF, a short description of the contents is presented first; next, conditions for the MF to become active are mentioned; and finally consequences of the MF being active are represented by causal influences introduced in the model.

Process fragments

Particle aggregation: this process causes space between soil particles to become smaller. In this case less molecules can infiltrate the soil because they are attracted by electric charges in soil molecules. Condition for activating this MF: the entity *Soil* exists. Consequence of having this MF active: the relation I+(*Aggregated soil*, *Particle aggregation rate*) is introduced in the model.

Deforestation: a human action that represents the removal of vegetation cover. Condition: structural configuration '*Human* modifies *Vegetation*'. Consequences: I+(*Land without vegetation cover*, *Deforestation rate*); and I–(*Land with vegetation cover*, *Deforestation rate*).

Infiltration: the infiltration process is responsible to carry the water from surface to inside the soil, increasing the underground water volume. Conditions: structural configurations '*Superficial Water* wets *Soil*' and '*Soil* contains *Underground water*'. Consequence: I+(*Underground water volume*, *Infiltration rate*).

Static fragments

Influences on particle aggregation: This MF captures the opposite influences from vegetation cover and the urban environment. Conditions: configurations '*Human* occupies *Land*', '*Human* modifies *Vegetation*' and '*Vegetation* covers *Land*'. Consequences: P–(*Particle aggregation rate*, *Vegetation cover*); and P+(*Particle aggregation rate*, *Urban areas*).

Urban areas and deforestation: A feedback loop on deforestation coming from urbanized areas is implemented by this MF. Condition: configuration '*Human* modifies *Vegetation*'. Consequence: P+(*Deforestation rate*, *Urban areas*).

Influences on infiltration: This MF shows that the quantity *Infiltration rate* receives influences from three state variables. Conditions: configurations '*Land* modifies *Water*'; '*Vegetation* covers *Land*' and '*Vegetation* protects *Water*'. Consequences: P–(*Infiltration rate*, *Aggregated soil*); P+(*Infiltration rate*, *Superficial water volume*); and P+(*Infiltration rate*, *Vegetation cover*).

Agent model fragments

Rainfall increases water in system: This MF describes changes in the water volume at soil surface due to the influence of an external agent, the climate. Condition: entity *Climate* exists. Consequence: I+(*Rain*, *Rainfall*).

Evaporation: describes changes of liquid water into vapour. Condition: entity *Atmosphere* exists. Consequence: I+(*Atmospheric vapour*, *Evaporation rate*).

Final remarks and ongoing work

This paper sets a plan for building qualitative models for the Riacho Fundo water basin case study in the project NaturNet-Redime, focusing on basic processes related to environmental sustainability. Following the framework established for building qualitative models in the project, we organized knowledge in a concept map from which the system structure was abstracted. Relevant processes are identified and causal models are designed. Expected behaviour and particular states of interest are described, and some scenarios and model fragments are presented to illustrate how the modelling effort shall progress.

The use of this framework for planning the modelling effort gives a broad overview of what will be the model, anticipates modelling problems and facilitates model documentation and communication. The use of this framework will also facilitate the integration of all the case studies into a unique library of model fragments. Given that it is a general goal of the NaturNet project to improve stakeholders understanding and, in doing so, to provide support for decision making, a curriculum is being developed along with the models, in order to organize educational activities that better explore these mdels.

We are planning to organize meetings with stakeholders at the WBC in the Riacho Fundo to assess the contents and the language used in the models. This practice will provide us means to assure that the models are adequate for the end users, for their understanding of the problems they have to make decisisons and consequences of their actions. The problems addressed in the Riacho Fundo basin are certainly more complex than the picture presented by this paper. Apart from including details about sustainability issues in the models, we foresee challenges for handling spatially distributed factors and phenomena occurring at different time scales. The models are currently being implemented in Garp3 and these research problems are being investigated as part of our ongoing work.

Acknowledgements

The work described in this paper is co-funded by the Comission of European Communities, project Naturnet – Redime, EU STREP, project number 004074. We would like to thank Bert Bredeweg, Tim Nuttle, Anders Bower and Jochem Liem for their comments during the preparation of this manuscript, and the project partners for discussions about to address sustainable development problems.

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