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A qualitative model on sustainability of the Riacho Fundo basin (Brasília, Brazil)

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Urbanisation seems to be the future of the global society (Egger, 2006). Understanding the consequences of land use change and the establishment of urban areas is essential for making sustainable this future. This paper describes an implemented qualitative simulation model about the Brazilian Riacho Fundo case study for the Project NaturNet – Redime[1]. This case study bridges the gap between case studies focussing on sustainability of water bodies in protected areas (River Mesta, Bulgaria, and the Delta of the Danube River, Romania), and case studies that focus on river management and rehabilitation, in areas strongly modified by human influence (River Kamp, Austria, and Rivers Trent and Grand Ouse, England). A complete description of the Riacho Fundo model is presented in Salles (2007).

The Riacho Fundo basin has been one of the most disturbed areas under Brasilia's influence area since the beginning of the new capital construction, in the 1950s. It was progressively impacted by the transformation of natural areas into rural and urban areas. These changes eventually created a densely populated urban structure where few rural properties still keep fruits and vegetables production and food processing industries. In these areas, springs, streams and natural vegetation patches are still protected and keep local biodiversity (see Salles and Caldas, 2006, for an overview of general aspects of the basin). A group of stakeholders prepared a list of relevant problems in the Riacho Fundo basin (Salles and Caldas, 2006). The uncontrolled land occupation and changes in land use were considered the most important problems. Deforestation, biodiversity loss, problems related to water resources management and low community participation in decision making process were also considered highly relevant. Accordingly, the following objectives were set for this modelling effort: (a) to improve understanding of environmental systems and problems that may affect sustainability in the basin; (b) to demonstrate the effects of human actions, both positively and negatively influencing different aspects of the Riacho Fundo basin system; (c) to provide support for stakeholders to learn about sustainability.

Sustainability is addressed in the Riacho Fundo model from three perspectives, *Rural*, *Semi-urban* and *Urban*. A perspective is a set of simulations that address a specific topic and answer a certain type of questions (Falkenhainer and Forbus, 1991). The *Rural* perspective focus on human use of natural resources for agricultural purposes. The *Semi-urban* perspective explores changes in land use that transform natural and agricultural areas into urban areas. The *Urban* perspective addresses the city and its physical infrastructure, particularly for the engineered drainage system for rainfall. These perspectives combine aspects of economy, governance, culture and human well being. The model was implemented in Garp3 (Bredeweg *et al*., 2006) using elements from the Qualitative Process theory (Forbus, 1984), and following a compostional modelling approach (Falkenhainer and Forbus, 1991). Accordingly, the model consists of a library of model fragments, stand-alone units that encode knowledge about structural configurations, situations and the mechanisms of change (processes). Two modelling primitives, direct influences (*I*+ and *I*–) and qualitative proportionalities (*P*+ and *P*–), are very important as they implement causal relations and mathematical relations that determine the qualitative values of the quantities. Table1 presents the main concepts addressed in each perspective.

[1] NaturNet-Redime, EU STREP, project number 004074. Available at www.naturnet.org.

	Perspectives		
Land use	**Urban**	**Semi-urban**	**Rural**
Main problems	Drainage system; flooded areas; transported garbage and damage caused by floods	Urbanization; water infiltration; and soil erosion	Erosion; loss of water resources and biodiversity
Economic features	Services: garages	Industry: textile and food industries	Agriculture: cattle; crops
Soil	Impermeable soil	Soil particle aggregation	Soil fertility
Water resources	Effects of uncontrolled flow of water run off and of the drainage system	Effects of erosion and underground water on springs and rivers	Effects of erosion and underground water on springs and streams
Biological entities	Mosquitos, Pathogens	Vegetation	Vegetation; Vertebrates; Capybara
Human	Economic activities; Human well-being: garbage and water related diseases	Economic activities	Economic activities
Agents	Rainfall	Urbanization	--
Sustainability	Control of diseases; Control of residues	Water quality; Control of residues	Soil fertilization; Reuse of residues

Table 1. Overview of the main concepts addressed by the Riacho Fundo model.

The structure of the Riacho Fundo system involves 32 entitites, and the model consists of 105 model fragments, being 24 implementing the *Rural*, 18 the *Semi-urban* and 30 the *Urban* perspective. Besides that, seven model fragments represent different types of water bodies, as for example, springs, streams and rivers, and 20 model fragments implement a general representation of economic activities, applied to the three perspectives (see Table 1). The current version of the model includes 19 simulations in the *Rural* perspective, 17 in the *Semi-urban* and 18 in the *Urban* perspectives.

Simulations within the *Rural* perspective provide answers to the following question: *what are the effects of soil protection and erosion on agricultural production, on rivers and streams, and on animal biodiversity in the rural area of the Riacho Fundo basin?* A simulation with the scenario 'Crop production influenced by soil nutrients and influences on stream and biodiversity' illustrates how the model provides answers to this question. The scenario is organized around the following entities and configurations: 'Vegetation' covers 'Rural soil'; 'Rural soil' next to 'Stream'; 'Stream' supports 'Capybara'; 'Rural soil' occupied by 'Rural RF'; finally, 'Rural RF' supports 'Crop' and 'Stream' supports 'Crop'. The simulation produces seven initial states and 65 states in total. Figure 1 shows the causal model obtained in state 7. Causality flow starts with changes in the vegetation: if *degradation* is greater than *regeneration*, vegetation *growth rate* is negative and causes *vegetation cover* to decrease. Besides being involved in two feedback relations (a negative influence to stabilize *growth rate* and a positive one to *regeneration*), *vegetation cover* influences *soil structure*, so that when the former decreases, the quality of soil structures also decreases, causing an increasing in the erosion process. Note that the entity 'Rural RF' represents land use, and therefore *eroded land* refers to the whole basin. As *soil structure* is decreasing, *eroded land* increases, and causes *nutrient* and *fertility* to decrease. *Removed soil* is also increasing, and causes the amount of *sediment* to increase. This change causes *depth* and *amount of water* in the stream to decrease. A reduction in the *amount of water* negatively influences the survival of mammals, such as the capybaras, causing a decrease in the local biodiversity. Crop production in the Riacho Fundo basin depends on water and nutrient availability. As both *amount of water* and *fertility* are decreasing, *resource inflow* to the production process decrease, influencing the *production rate*. A negative rate causes agricultural *products* to decrease. Associated to the production process, both *residues* in general and the *pesticides* particular also decrease. This way, the model establishes a causal link between changes in vegetation cover and changes in soil fertility, amount of water, local biodiversity and crop production. As ambiguity is inherent to qualitative

representations, it is assumed that some quantities correspond to other quantities (see Q relations in Figure 1). This modelling primitive implements the notion that two correspondent quantities always have specific pairs of values simultaneously. The effect is a reduction in the number of states in the simulation.

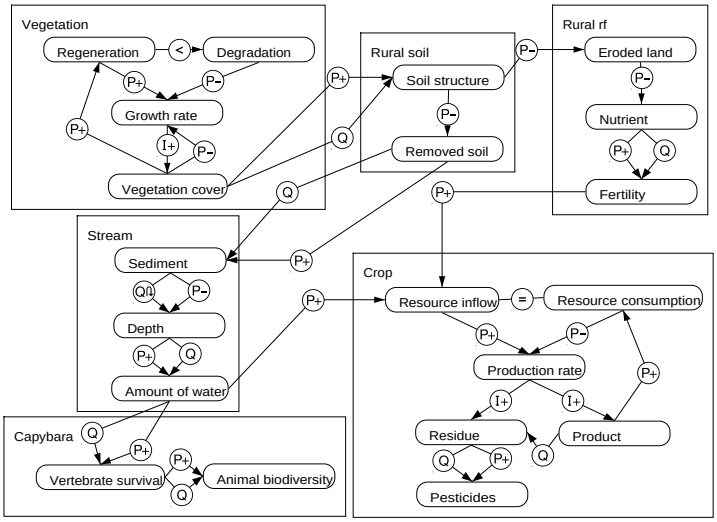

Figure 1. Causal model in state 7 of the simulation 'Crop production influenced by soil nutrients and influences on stream and biodiversity', *Rural* perspective of the Riacho Fundo model.

Simulations within the *Semi-urban* perspective provide answers for the question: *how changes in soil features, under the conflicting forces of urbanization and natural vegetation dynamics, may affect functional springs, rivers and the industrial production in the Riacho Fundo basin?* Finally, simulations in the *Urban* perspective answer the question: *what are the benefits of having a good infrastructure for the drainage of rain water in the urban area of Riacho Fundo with respect to soil protection, economic damages caused by garbage, and the human well being?* Concluding, the model provide answers to relevant questions about sustainability. Ongoing work includes extending the coverage of rural and urban features. From the content point of view, the Riacho Fundo model has the potential for significantly improving stakeholders' understanding about their everyday problems.

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