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D6.7.1 Library of reusable QR model fragments

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Abstract

Dealing with large domains of knowledge represented in qualitative models, as sustainable development, requires means to organize and access knowledge encoded in the library of model fragments in order to create simulation models that are just sufficient to answer specific questions. This document describes the Library of model fragments developed from the combination of case study models produced in the Project NaturNet – Redime and additional models about indicators of the Millennium Development Goals. The Library consists of 414 model fragments and 202 simulations organized by means of perspectives from which knowledge about sustainability encoded in the library can be explored. A perspective is defined as a set of simulations that address a specific topic. Two groups of perspectives were developed for the Library: (a) case study views on sustainability, including seven perspectives defined in accordance to the five case studies and the two models about deforestation and global warming; in this case, the simulations are organized as in the case study models; (b) thematic perspectives on sustainability, including 14 sets of simulations addressing relevant topics such as natural systems, environmental effects of human activities, education and trainning for sustainability, governmental plans and actions, human well being. In this case, each perspective consists of selected simulations from different models. We conclude that this Library represents a valuable tool for dissemination of sustainable development concepts and also an important achievement for Qualitative Reasoning modelling research and development.

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Content

1 INTRODUCTION

The objective of this Deliverable is to present a library of re-usable model fragments (MF) created to capture essential phenomena relevant for understanding issues related to sustainable development (SD), and to organize the simulations in meaningful way. The contents of the library are the results obtained in NaturNet – Redime Project case studies and in additional models about the Millenium Development Goals (MDG) (Garrity , 2004; Salles, 2005). As the Library of model fragments includes a broad range of knowledge coming from different disciplines, it is necessary to define means to explore the library and select clusters of concepts that may be understood and used as components of curricula for learning about sustainability (Colby, 1991; Dodds,1997; Daily et al., 1997).

The solution for this problem is to build up *perspectives* as viewpoints to sustainability, using *modelling assumptions* (*sensu* Falkenhainer and Forbus, 1991) to capture knowledge about sustainability. A perspective defines a subset of simulation models that can be created to achieve a particular goal, that is, to answer questions of a particular type. Creating a perspective requires the selection of a sub-system within the larger system of interest, which includes a sub-set of entities and potentially a sub-set of the entities' features (quantities). In other words, a perspective is a set of simulations that address a specific subject and have in common specific concepts within a domain knowledge and some modelling elements (as entities and quantities).

Perspectives can be implemented by using mechanisms for automated search of model fragments in a library, a long standing problem for the Qualitative Reasoning community of researchers (see, for example, Falkenhainer and Forbus, 1991, and other references in section 6). From this point of view, perspectives serve an organizational function as they guide the modeller in selecting appropriate assumptions, structural relations and scenarios. Perspectives are thus useful in defining and constraining a simulation, taking into consideration certain aspects of the encoded knowledge while ignoring the rest. Depending on which perspective is adopted, different entities, quantities, values, and causal relationships are included in the simulation.

Two groups of perspectives are used to organize this Library of model fragments: (a) case study-based perspectives, and (b) thematic-based perspectives. As described in this document and elsewhere (Deliverable 6.4.2 and in Salles et al., 2007), case study-based perspectives can be implemented using explicitly represented assumptions, as well as other modeling primitives, including hierarchies of entities and model fragments, attributes, alternative quantity spaces for key quantities and alternative representations of key concepts. These modelling elements are used by the reasoning engine to select model fragments to be included in the simulation models and therefore to express relevant knowledge to the perspective (Bredeweg et al. 2006).

Thematic-based perspectives are sets of simulations selected from the case studies in accordance to relevant themes for the sustainability discussion. The selection of simulations is not automated. Instead, the approach taken here is to suggest for the user which simulations could be used to explore specific concepts. This way, the concepts expressed in the models are used to offer to stakeholders additional ways of organizing the knowledge contents of the Library.

This document is organized as follows: in section 2, a brief discussion about the use of perspectives and modelling assumptions presents the theoretical background used to organize the Library, in particular the case study-based perspectives. In section 3, the input models used to build the Library are summarized. Implementation aspects of the Library are presented in section 4, and in section 5 details of the simulations are discussed in the context of thematic perspectives. A general discussion of problems found during this task and the solutions adopted is presented in section 6 and the concluding remarks can be found in section 7. The Library is available on line at www.naturnet.org; and http://hcs.science.uva.nl/QRM.

2 ASSUMPTIONS AND PERSPECTIVES

Conceptually, modelling assumptions fall into two categories: *simplifying* and *operating* assumptions (Falkenhainer and Forbus, 1991). In this section these classes of assumptions are presented, along with some typical examples.

2.1 Symplifying assumptions

Simplifying assumptions are used to make explicit how knowledge details such as the underlying perspective, approximations, and level of granularity are represented in the model fragments. Simplifying assumptions are classified as (a) ontological assumptions, to provide the vocabulary used in the model, explicating what kinds of things exist and what sort of relationships between them can be held; (b) grain assumptions, to define the level of details represented in the model, perhaps aggregating some features and ignoring others; (c) approximation assumptions, to make models that are easy to use, sometimes at the cost of accuracy; and, often intertwined with approximation assumptions, (d) abstraction assumptions, used to reduce the complexity of the modelling language, usually reducing information available and increasing ambiguity.

2.2 Operating assumptions

Operating assumptions are used to manage complexity. In a way, they give focus to the simulation, by implementing constraints so that the model describes the behaviour relevant for answering specific questions. Three types of operating assumptions are considered here: (a) local restrictions: restrictions on quantity values implemented by means of inequalities between quantities and constants (e.g. number_of >0); (b) operation mode: a ‘general assumption’ that controls a collection of local restrictions; and (c) steady-state assumptions: determine that all derivatives for some class of parameters have value zero. Ultimately, operating assumptions increase the efficiency of the simulation by ruling out entire classes of behaviour (e.g. immigration and emigration in population dynamics), and by indicating the range of parameter values for which such approximations are valid (for example, ‘birth rate’ can only exist when ‘number_of’ >0).

As mentioned above, assumptions and other modelling elements were used first to implement the case study models and then to integrate them into the Library. These issues are not discussed in this Deliverable. In the following sections we focus mostly in the causal model produced in simulations and, due to lack of space, we'll leave aside discussions about the model fragments and details of the simulations. The interested reader can found details about the implementation in the respective Deliverables (D6.2.1 and D6.2.2; D6.3.1 and D6.3.2; D6.4.1 and D6.4.2; D6.4.1 and D6.5.2; and D6.6.1 and D6.6.2 – available in www.naturnet.org) and in the papers presented at the 21st International Workshop on Qualitative Reasoning (Cioaca et al., 2007; Nakova et al., 2007; Noble et al., 2007; Salles et al. 2007; Zitek et al., 2007. A study about the implementation of perspectives in the Riacho Fundo model was presented at the 21st International Workshop on Qualitative Reasoning (cf. Salles et al. 2007).

3 INPUT FOR THE LIBRARY

The Redime part of the Project NaturNet-Redime includes five case studies, each resulting in one model. These models, along with two additional models developed in the context of the Millennium Development Goals are included in the Library. This section presents an overview of these input models.

3.1 Models from the Naturnet-Redime case studies

3.1.1 Basis QR case study Danube Delta in Romania (Task 6.2)

The Romanian case study focus on physical, chemical, and biological processes in Danube Delta Biosphere Reserve, including aquatic ecosystem morphological changes under pressures from human activities such as eutrophication and water pollution processes, and their effect on human health and biotic component development. The main results are described in D6.2.1 and D6.2.2.

3.1.2 Basis QR case study River Mesta in Bulgaria (Task 6.3)

This case study focus on physical chemical and biological processes for understanding and forecasting effects of erosion, irrigation, water pollution and other urban and/or industrial pollution on abiotic and biotic structures of the ecosystem. The main results are described in D6.3.1 and D6.3.2.

3.1.3 Bridging QR case study Riacho Fundo in Brazil (Task 6.4)

The focus of the Brazilian case study is the effects of deforestation, erosion, water pollution and the creation of urban areas in the Riacho Fundo (Paranoá Lake basin, Brasília) on biological populations and communities, biodiversity, habitats and ecosystems; social, economic, and cultural processes and values; and the effects on economic activities and human well being. The model was divided in three submodels, that consist in three perspectives for approaching sustainability in the basin: Rural, Semi-urban and Urban Riacho Fundo. The main results are described in D6.4.1 and D6.4.2.

3.1.4 Collaborative QR case study River Kamp in Austria (Task 6.5)

Romanian case study Focus on ecosystem, social, economic and cultural processes and integrated management related to restoration of rivers and catchment planning in Austria. This way, the model gives insights in the main driving forces of the riverine ecosystem and explores aspects of stakeholder participation and the preparation and implementation of sustainability plans. The model was divided in two submodels, one addressing issues related to water abstraction and energy generation, and the second exploring different aspects of stakeholder participation. The main results are described in D6.5.1 and D6.5.2.

3.1.5 Collaborative QR case study River Trent and Yorkshire River Ouse (Task 6.6)

Focus on ecosystem, social, economic and cultural processes and integrated management of two contrasting rivers in England, the rivers Trent and Ouse, which suffer from different degrees of water quality, flow regulation and habitat degradation problems. The salmon and bream life cycles are used as a sort of biological indicators of environmental problems and management efficacy. The main results are described in D6.6.1 and D6.6.2.

3.2 Models from the Millennium Development Goals

Besides the models produced in the case studies, the Library includes two models: Deforestation and Global warming. These models focus on indicators of sustainability selected for monitoring the Millenium Development Goals (Salles, 2005).

3.2.1 Deforestation model

The model shows the consequences of deforestation: reduction of the area covered by natural vegetation (indicator 25, Target 9, MDGoal 7) loss of biodiversity (indicator 26, Target 9, MDGoal 7), reduction in chances of developing technological products that would add to the Gross Domestic Product (GDP). Deforestation also increases the area without natural cover of vegetation. This situation speeds up the erosion process, the reduction of water reservoires and, consequently of human water supply and of agricultural production.

3.2.2 Global warming model

The model shows how changes in offer and demand of available energy due to market oscillations may affect the use of petrol in industry, transport and domestic activities. The model shows also how changes in these sectors may be related with atmospheric pollution, including CO2 emissions (MDG7 indicator 28, Target 9, MDGoal 7), domestic atmospheric pollution, caused by the smoke produced by the use of solid fuel (wood, vegetal coal), the MDG7 indicator 29 (Target 9, MDGoal 7) and the incidence of respiratory diseases.

4 IMPLEMENTING THE LIBRARY

The Library consists of 112 entities, 1 attribute, 60 configurations, 201 quantities, 22 quantity spaces, 202 simulation scenarios, 414 model fragments, 24 agents and 45 modelling assumptions. These model components represent a medium level of integration of the input models. In fact, there is a common structure and improved representations of entities and model fragments, but it is still possible to explore them as separate models.

4.1 Overview of the input models

The following table decribes the re-arranged models as they are included in the Library:

Model	Static MF	Process MF	Agent MF	Total MF	Total Scenarios
Water abstraction (Aw)	30	9	2	41	31
Deforestation (D)	9	0	3	12	05
Danube Delta (Dd)	38	15	2	55	24
Economy (E)	16	4	0	20	07
Global warming (Gw)	6	0	1	07	03
Rural Riacho Fundo (Rfru)	19	4	0	23	18
Semi-urban Riacho Fundo (Rfsu)	12	6	1	19	18
Urban Riacho Fundo (Rfur)	27	9	1	30	18
River Mesta (Rm)	10	7	4	21	18
Stakeholder participation (Sp)	31	9	4	44	42
Catastrophic event (Sp)	5	2	0	07	03
Salmon and Bream (Uk)	108	1	12	121	15
Water body description	7	0	0	07	0
TOTAL	318	66	30	414	202

4.2 Entities

The Library of model fragments is organized around 112 entities. A number of them are common to more than one model, and some are model-specific. In any case, knowledge assigned to entities at higher levels of the tree is inherited by the entities that are below them, as for example the quantity *amount of water* assigned to the entity ‘Water body’ is inherited by rivers, streams and springs.

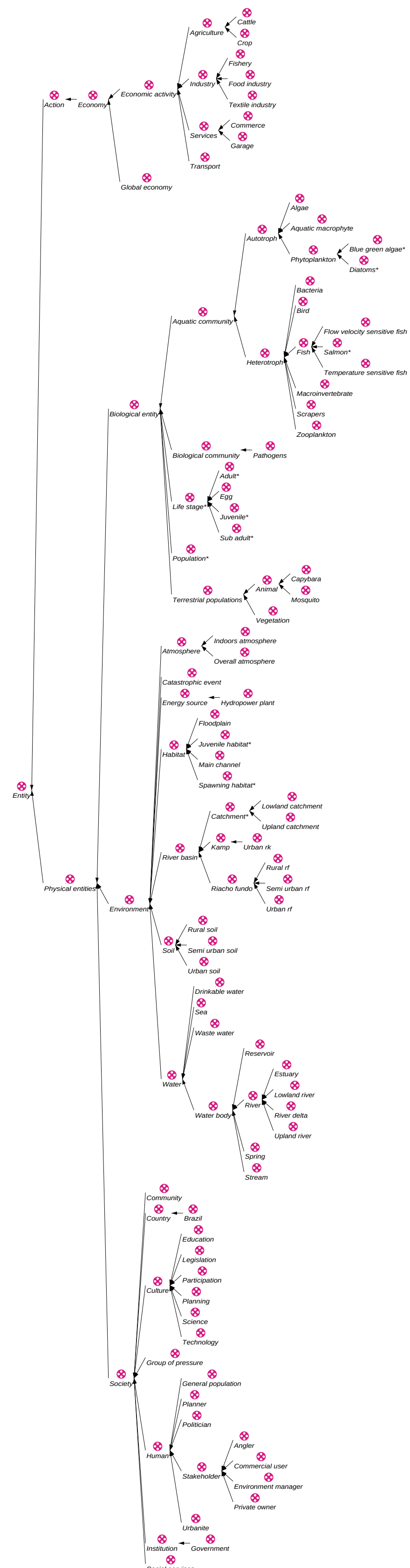

Figure 1. Entity hierarchy used in the Library of model fragments.

4.3 Assumptions

The Library includes 45 modelling assumptions, classified as operating and sympolifying assumptions as shown in the figure below:

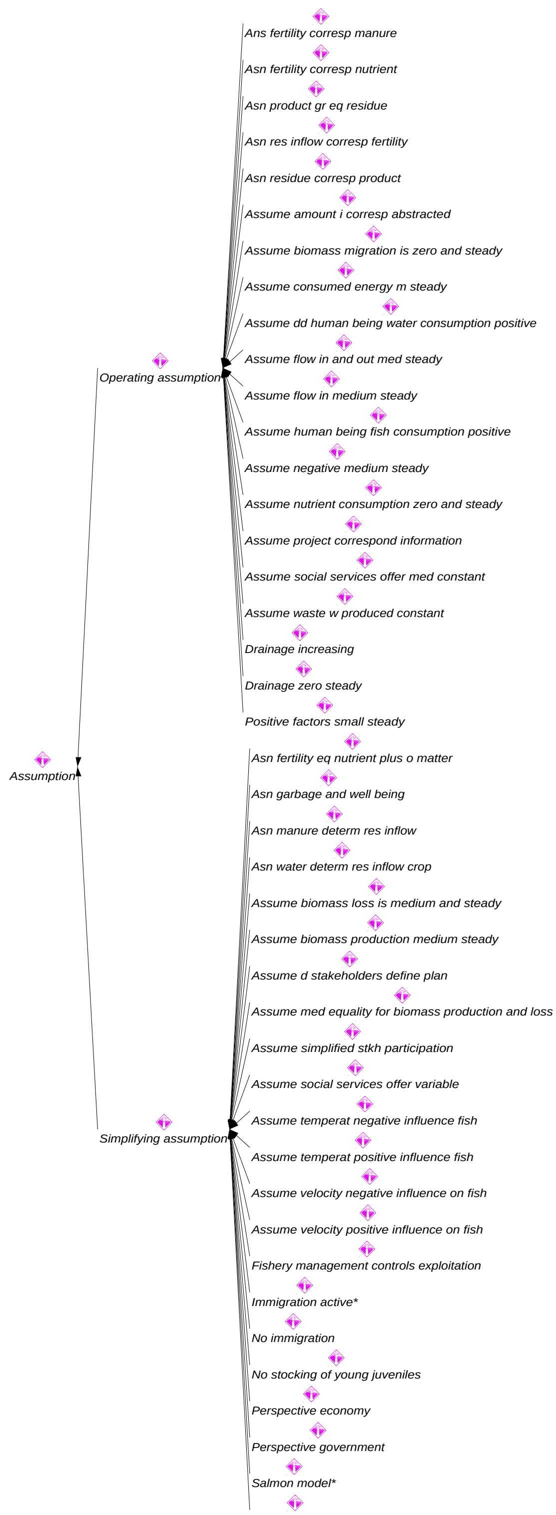

Figure 2. Assumptions used in the Library of model fragments.

4.4 Agents

The agents used in the Library are presented in the following figure.

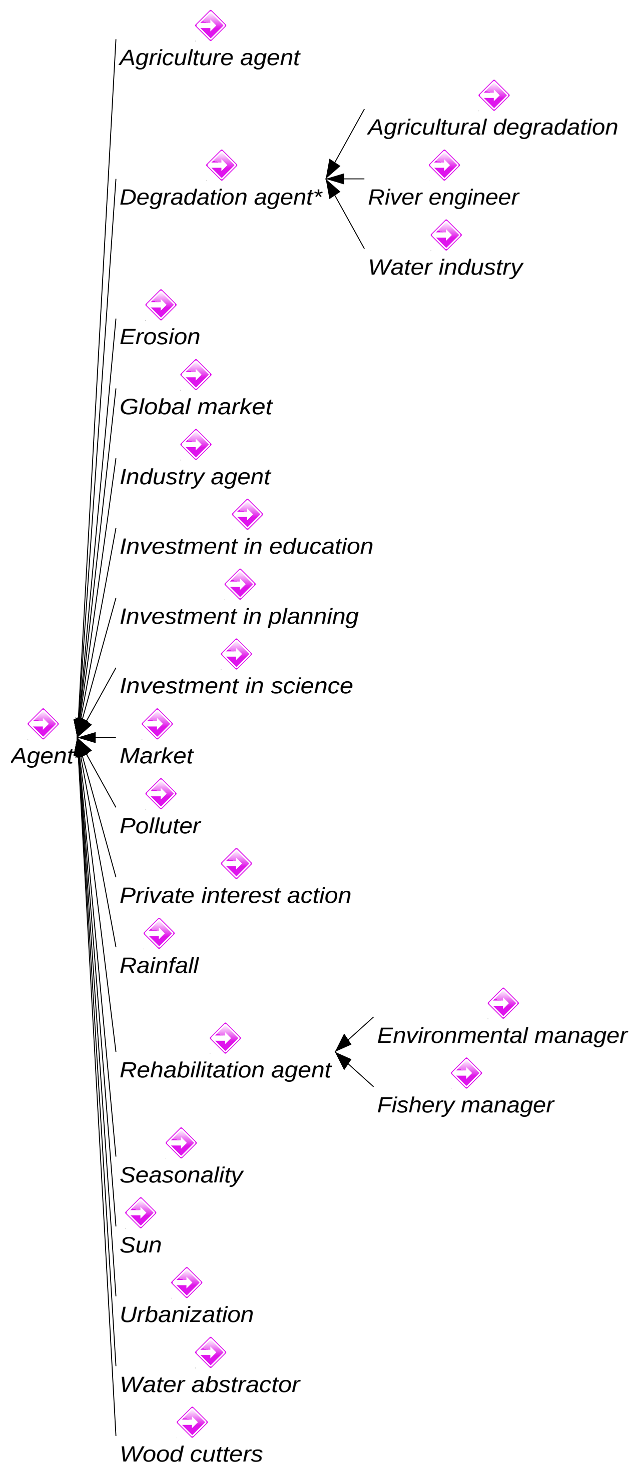

Figure 3. Agents used in the Library of model fragments.

5 PERSPECTIVES

It is possible to explore the Library in many ways. Two of them are discussed here: (a) by creating perspectives based in the input models, as they were presented, and (b) by creating thematic perspectives. Initially, the design of the five case studies reflects the intention of covering different but complementary sets of sustainability problems: basic phenomena related to natural systems; phenomena related to changes in land use, moving from natural to urban ecosystems; management activities related to human impacted water basins. Besides that, studies about the Millennium Development Goals addressed problems that are not included in the case studies. Thematic perspectives are simulations that can be used to explore relevant topics for the sustainability discussion, as for example, natural systems, the impact of human actions, economic activities, legislation, governmental actions, management actions for sustainable development. As shown below, all the input models explore parts of this knowledge. In this section the two approaches are discussed.

5.1 Case study-based perspectives

Taking the results of the input models, as they were presented, seven high level perspectives to approach sustainability issues were developed, as described in the following table:

Perspectives	Input models	Observations
Natural	Danube Delta (Dd), River Mesta (Rm)	Basic case studies producing models exploring nutrient cycling, food webs, the effects of agriculture and industrial pollution, the dynamics of dissolved oxygen in water bodies
Rural	Rural Riacho Fundo (Rfru)	Model exploring the effects of deforestation on erosion, soil fertility, water resources, biodiversity and agricultural (crops and cattle) activities
Semi-urban	Semi-urban Riacho Fundo (Rfsu)	Model exploring the effects of urbanization, including soil erosion and the degradation of springs and streams, water infiltration and underground water, and the use of water resources in industrial activities (textile and food industries)
Urban	Urban Riacho Fundo (Rfur)	Model compares the urban situation in absence and in presence of an engineered drainage system with respect to the main consequences: floods, economic damage, transported garbage, water related diseases and the human well being
Natural resources exploitation	Water abstraction (Aw), Deforestation (D),	Water abstraction model explores the effects of water abstraction to produce energy on the amount of water, on fish populations;

	Global warming (Gw)	Deforestation model presents the effects of deforestation on the use of biodiversity, erosion and water resources; Global warming model presentes the effects of pollution caused by petrolleum and solid fuels burning on human health and global warming.
Natural environment rehabilitation	Salmon and Bream (Uk)	This model explores the dynamics of fish populations and the benefits from improving natural habitats and stocking.
Social	Stakeholder participation (Sp)	This model explores a number aspects related to stakeholder participation in the decision-making process, including legislation, governmental actions, sustainability plans, education and technological solutions.

These high level perspectives may be interesting for in-depth studies on sustainability, as they are extensive explorations of typical features of some regions. However, these perspectives are too general for some stakeholders, as discussed below.

5.2 Thematic-based perspectives

A thematic-based approach to the Library exploitation was created in order to expand the options available to the users. Following this intuition, 14 perspectives were created, combining simulations obtained from different case study models, as shown in the following table:

Perspectives	Topics for sustainability issues	Source models
(I) Natural systems	Rivers; vegetation; macrophytes; blue green algae; diatoms; phyto and zooplankton; animals; population growth; biodiversity; foodwebs; soil integrity; fertility; nutrients.	Dd, Rm, Rfru, Sp, Uk
(II) Natural disasters	Generic aspects of disasters; floods in urban areas.	Sp, Rfur
(III) Human explores natural resources	Land use changes; biodiversity exploitation; degradation and regeneration of vegetation.	Rfru, Rfsu, Uk
(IV) Environmental effects of human activities (in interaction with natural factors)	Deforestation; degradation and regeneration of vegetation; erosion; water abstraction; different types of pollution; changes in biological systems. Effects of human actions may be combined to effects of natural factors.	Dd, Rm, D,
(V) Energy	Energy generation and environment; commercial use of energy; consequences of the use of petrolleum on global warming;	Aw, Gw

	trade-off between the use of petrolleum and the use of solid fuels in poor households.	
(VI) Economy	Mechanisms involving resources offer and consumption, production rate, products, residues and jobs in the three sectors (agriculture, industry and services) of economic activities; different types of resources used in economic activities; different types of residues and pollutants produced by economic activity; (un)balanced proportions of products and residues; influences on GDP of technological innovation exploring biodiversity, uses of water resources and agriculture.	E, Dd, D, Rfru, Rfsu, Rfur
(VII) Education and trainning	Education improves society's education level; training of planners; qualification of stakeholders for participation.	Sp
(VIII) Science and Technology	Involvement of the academic community in the development of technological solutions for sustainability.	Sp
(IX) Legislation	Centralizing and decentralizing legislation influence access to information and to the decision making process. Therefore, it may stimulate or inhibit stakholder participation.	Sp
(X) Stakeholder participation	Participation on the decision making process facilitated by decentralizing legislation and by motivated by participation in projects; access to sustainability planning.	Sp
(XI) Governmental plans and activities	Preparation of sustainability plans: influences from, prepared planners, possible technological solutions, stakeholders and groups of interest and. Emergency actions in catastrophes. Sustainable and non-sustainable governmental actions towards basin restoration and human well being.	Sp
(XII) Management actions for sustainability	Human activities may have a positive effect towards sustainability; for example, pollutants may become input for productive activitites (manure in agriculture production). Also, removal of weirs, rehabilitation of spawning habitats and other measures may bring back fish populations. rehabilitation of riverine ecosystems;	Rfur, Uk
(XIII) Human health	Pollution related diseases: acute and chronic respiratory diseases; heavy metal and nutrient contamination acquired by drinking water and eating fish. Water related pathogens in flooded areas.	Gw, Dd, Rfur

(XIV) Human well being	Positive and negative factors related human well being: pathogens, garbage and mosquitos; effects of sustainable and non-sustainable governmental actions.	Rfur; Sp

5.3 Perspectives and simulations

The following tables describe the whole list of simulations included in the Library, with a brief summary of the contents of each simulation and relations to the 14 perspectives created to explore knowledge encoded in the Library. Note that the description of the simulation always ends with two numbers between brackets. These numbers represent the number of initial states, and the total number of estates produced in the simulation.

5.3.1 Water abstraction model (River Kamp case study, Austria)

#	Scenario	Summary of the simulations	Perspectives
(1)	Aw sce01a Only water	Only the entity is used to represent a river. (01 stt)	I
(2)	Aw sce01b Only river and its water	Two entities to represent the river and its water. (02 stt)	I
(3)	Aw sce01c Only river water and flow quantity	Two entities and two quantities to represent the river and its water. (02 stt)	I
(4)	Aw sce01d Only river water temperature quantity	Two entities and two quantities to represent the river and its water. (02 stt)	I
(5)	Aw sce02a Water in the river increasing	Only the factors related to the river show how inflow and outflow may become balanced. (01, 04 stt)	I
(6)	Aw sce02b Water in the river decreasing	Only the factors related to the river show how inflow and outflow may become balanced. (01, 04 stt)	I
(7)	Aw sce02c Water in the river steady	Only the factors related to the river show how inflow and outflow are balanced (an assumption that is used in the rest of the simulations). (01, 01 stt)	I
(8)	Aw sce03 Agent abstracts water from river	Agent abstracts water and changes river parameter (amount of water). (01, 07 stt)	III, IV
(9)	Aw sce04 Agent abstracts water from river and fills in reservoir	Agent abstracts water and changes river parameter (amount of water) and puts it in a reservoir. (01, 08 stt)	III, IV
(10)	Aw sce05a Agent abstracts	Agent abstracts water and changes river parameters (amount of water,	III, IV

	water from volume river high and physical factors	depth, temperature, velocity). (01, 07 stt)	
(11)	Aw sce05b Agent abstracts w from river max and physical factors	Agent abstracts water and changes river parameters (amount of water, depth, temperature, velocity). (01, 08 stt)	III, IV,
(12)	Aw sce06 Growth of temperature fish	Population growth process of temperature fish (could be any fish). (03, 08 stt)	I
(13)	Aw sce07a Water from river physical factors and positive temperature fish	Agent abstracts water and changes river temperature and affects fish. (01, 20 stt)	IV
(14)	Aw sce07b Water from river physical factors and negative temperature fish	Agent abstracts water and changes river temperature and affects fish. (01, 24 stt)	IV
(15)	Aw sce07c Water from river physical factors and positive velocity fish	Agent abstracts water and changes river velocity and affects fish. (01, 24 stt)	IV
(16)	Aw sce07d Water from river physical factors and negative velocity fish	Agent abstracts water and changes river velocity and affects fish. (01, 20 stt)	IV
(17)	Aw sce07e Water from river and positive temperature and negative velocity fishes	Agent abstracts water and changes river temperature and velocity and affects two types of fish. (01, 48 stt)	IV
(18)	Aw sce07f Water from river and negative temperature and negative velocity fishes	Agent abstracts water and changes river temperature and velocity and affects two types of fish. (01, 56 stt)	IV
(19)	Aw sce07g Water from river and positive temperature and positive velocity fishes	Agent abstracts water and changes river temperature and velocity and affects two types of fish. (01, 68 stt)	IV
(20)	Aw sce08a From river to reservoir and physical factors	Agent abstracts water and changes river parameters (amount of water, depth, temperature, velocity). (01, 07 stt)	III
(21)	Aw sce08b From river to reservoir and positive temperature fish	Agent abstracts water and changes river temperature and affects fish. (01, 20 stt)	IV
(22)	Aw sce08c	Agent abstracts water and changes	IV

	From river to reservoir and negative temperature fish	river temperature and affects fish. (01, 24 stt)	
(23)	Aw sce08d From river to reservoir and positive velocity fish	Agent abstracts water and changes river velocity and affects fish. (01, 24 stt)	IV
(24)	Aw sce08e From river to reservoir and negative velocity fish	Agent abstracts water and changes river velocity and affects fish. (01, 20 stt)	IV
(25)	Aw sce08f From river to reservoir and positive temperature negative velocity fishes	Agent abstracts water and changes river temperature and velocity and affects two types of fish. (01, 48 stt)	IV
(26)	Aw sce09a Energy production only	Mecanism of energy generation in a hydropower plant. (01, 18 stt)	III, V
(27)	Aw sce09b From river to reservoir and energy production	Agent abstracts water and moves the mecanism of energy generation in a hydropower plant. (01, 21 stt)	III, V
(28)	Aw sce09c From river to reservoir energy production and profit	Agent abstracts water and moves the mecanism of energy generation in a hydropower plant and private owner makes profit. (01, 21 stt)	III, V, VI
(29)	Aw sce10a From river to reservoir energy production profit and fish	Agent abstracts water, generates energy and private owner makes profit; it changes physical factors and affects fish. (03, 22 stt)	IV, V, VI
(30)	Aw sce10b From river to reservoir energy production profit and two fishes	Agent abstracts water, generates energy and private owner makes profit; it changes physical factors and affects two fishes. (03, 50 stt)	IV, V, VI
(31)	Aw sce10c From river to reservoir energy production profit and other two fishes	Agent abstracts water, generates energy and private owner makes profit; it changes physical factors and affects two fishes. (03, 54 stt)	IV, V, VI

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.2 Deforestation model (MDG studies, Brazil)

#	Scenario	Summary of the simulations	Perspectives
(32)	D sce01	Agent cuts the trees and creates	IV, III

	Deforestation impact on vegetation	land with no vegetation; this affects biodiversity. (01, 04 stt)	
(33)	D sce02 Deforestation impacts on new food and medicines	Agent cuts the trees and loss of biodiversity reduces opportunities for new food and medicines, that would increase GDP. (01, 04 stt)	VI, III
(34)	D sce03 Deforestation impact on land	Deforestation reduces area covered by vegetation and causes erosion, which in turn affects agriculture. (01, 04 stt)	VI, III
(35)	D sce04 Deforestation impact on land and water	Deforestation reduces area covered by vegetation and causes erosion, which in turn affects agriculture and uses of water resources. (01, 04 stt)	VI, III
(36)	D sce05 Deforestation impact on GDP	Deforestation reduces area covered by vegetation and causes erosion, which in turn affects agriculture, uses of water resources, population without water and decrease in GDP. (01, 04 stt)	VI, III, XIV

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.3 Danube Delta model (Danube Delta case study, Romania)

#	Scenario	Summary of the simulations	Perspectives
(37)	Dd sce01a Diatoms growth process in low nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and diatoms in the Delta, with a specific scenario. (04, 44 stt)	IV
(38)	Dd sce01b Diatoms growth process in medium nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and diatoms in the Delta, with a specific scenario. (04, 23 stt)	IV
(39)	Dd sce01c Diatoms growth process in high nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and diatoms in the Delta, with a specific scenario. (04, 17 stt)	IV
(40)	Dd sce02a Blue green algae growth process in medium nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and blue green algae in the Delta, with a specific scenario. (04, 27 stt)	IV

(41)	Dd sce02b Blue green algae growth process in high nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and blue green algae in the Delta, with a specific scenario. (04, 33 stt)	IV
(42)	Dd sce03a Macrophytes growth process in low nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and aquatic macrophytes in the Delta, with a specific scenario. (04, 97 stt)	IV
(43)	Dd sce03b Macrophytes growth process in medium nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and aquatic macrophytes in the Delta, with a specific scenario. (04, 27 stt)	IV
(44)	Dd sce03c Macrophytes growth process in high nutrient inflow	Water from Danube river flows into the Delta and brings farming generated nutrient runoff; this affects physical factors and aquatic macrophytes in the Delta, with a specific scenario. (04, 33 stt)	IV
(45)	Dd sce04 Diatoms and zooplankton growth process	Food web involving diatoms e zooplankton, with cyclic behaviour. (01, 20 stt)	I
(46)	Dd sce05 Zooplankton and fish growth process	Food web involving zooplankton and fish, with cyclic behaviour. (01, 20 stt)	I
(47)	Dd sce06 Fish and bird growth process	Food web involving fish and bird, with cyclic behaviour. (01, 20 stt)	I
(48)	Dd sce07a Macrophytes and macroinvertebrates medium growth	Food web involving macrophytes and macroinvertebrates, with cyclic behaviour. (01, 12 stt)	I
(49)	Dd sce07b Macrophytes and macroinvertebrates low growth	Food web involving macrophytes and macroinvertebrates, with a cyclic behaviour. (01, 20 stt)	I
(50)	Dd sce08 Nutrients diatoms and zooplankton	Food web involving nutrients available in Danube Delta and the effects on diatoms and the zooplankton, no cyclic behaviour. (03, 48 stt)	I
(51)	Dd sce09 Diatoms zooplankton and fish	Food web involving diatoms, zooplankton and fish, with cyclic behaviour. (01, 56 stt)	I
(52)	Dd sce10a	Food web involving zooplankton, fish	I

	Zooplankton fish and birds	and birds, with cyclic behaviour (01, 56 stt).	
(53)	Dd sce11 Diatoms zooplankton fish and birds	Food web involving diatoms, zooplankton, fish and birds, with cyclic behaviour (01, 401stt).	I
(54)	Dd sce12 Water pollution process	Farming and industries in the Danube River catchment area produce nutrient and heavy metal runoffs that pollutes the river; this polluted water flows into the Delta, where there are also cyanotoxins. (03, 11 stt)	IV
(55)	Dd sce13 Water pollution and aquatic biodiversity	Farming and industries in the Danube River catchment area produce nutrient and heavy metal runoffs that pollutes the river; the polluted water flows into the Delta, where there is aquatic biodiversity. (03, 20 stt)	IV
(56)	Dd sce14 Water pollution and black sea biodiversity	Farming and industries in the Danube River catchment area produce nutrient and heavy metal runoffs that pollutes the river; the polluted water flows ino the Delta, from where it flows to the Black sea, and affects its biodiversity. (03, 11 stt)	IV
(57)	Dd sce15 Human health influenced by water quality	Humans drink water from the Danube Delta, and are contaminated by polluted water (both by nutrients and heavy metals). (01, 10 stt)	XIII
(58)	Dd sce16a Health influenced by fish quality biomass production high	Humans eat fish from the Danube Delta, and are contaminated by heavy metals (bioaccumulation). (01, 03 stt)	XIII
(59)	Dd sce16b Health influenced by fish quality biomass production low	Humans eat fish from the Danube Delta, and are contaminated by heavy metals (bioaccumulation). (01, 07 stt)	XIII
(60)	Dd sce16c Health influenced by fish quality biomass loss low	Humans eat fish from the Danube Delta, and are contaminated by heavy metals (bioaccumulation). (03, 16 stt)	XIII

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.4 Economy model (Riacho Fundo case study, Brazil)

#	Scenario	Summary of the simulations	Perspectives
(61)	E sce01a Rural activity no assumptions	A generic mecanism applicable to all the economic activities: resource inflow / resource consumption / production rate / product and residue and jobs. Residues may affect the environment. (03, 14 stt)	VI, IV
(62)	E sce01b Rural activity product greater equal residue	A generic mecanism applicable to all the economic activities: resource inflow / resource consumption / production rate / product and residue and jobs. Products are assumed to be greater or equal Residues. (03, 13 stt)	VI, IV
(63)	E sce01c Rural activity residue correspond to product	A generic mecanism applicable to all the economic activities: resource inflow / resource consumption / production rate / product and residue and jobs. Residues are assumed to correspond to Products. (03, 08 stt)	VI, IV
(64)	E sce02a Industry activity no assumptions	The mecanism applies to all the economic activities, with no assumption, results in many value combinations of products and residues. Residues may affect the environment. (03, 14 stt)	VI, IV
(65)	E sce02b Food industry assume residue correspond to product	The mecanism applies to all the economic activities, with the assumption that the amount of residues correspond to products. (03, 08 stt)	VI, IV
(66)	E sce03a Cattle assume residue correspond to product	The mecanism applies to all the economic activities with the assumption that the amount of residues correspond to products. Residues may either affect the environment or become organic fertilizer. (03, 08 stt)	VI, IV, III
(67)	E sce03b Crop assume product greater or equal residue	The model of the mecanism that applies to all the economic activities with another assumption, that the amount of products is greater or equal the amount of residues. (03, 09 stt)	VI, IV

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.5 Global warming model (Millennium Development Goals, Brazil)

#	Scenario	Summary of simulations	Perspectives
(68)	Gw sce01 Petroleum global market	Market oscillations determine the amount of petrolleum available. Cyclic behaviour is observed. (02, 08 stt)	V, VI
(69)	Gw sce02 Petroleum and atmosphere	Petrolleum availability determines its use in industry. Environmental consequences include greenhouse gases and other pollutants emission and temperature change. (02, 24 stt)	V, IV, VI
(70)	Gw sce03 Solid fuel and global warming	Petrolleum availability determines its use in industry and household consumption. When it is scarce, poor people uses solid fuels. Altogether the emissions produce respiratory diseases and global warming. (02, 24 stt)	V, IV, XIII, VI

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.6 Rural Riacho Fundo model (River Kamp case study, Austria)

#	Scenario	Summary of simulations	Perspectives
(71)	Rfru sce01a Vegetation dynamics only	Vegetation growth is modelled as the result of a balance between regeneration and degradation. (07, 22 stt)	I
(72)	Rfru sce01b Vegetation dynamics only	Vegetation growth is modelled as the result of a balance between regeneration and degradation, with different initial values. (03, 12 stt)	I
(73)	Rfru sce02 Vegetation dynamics and soil	Vegetation is related to soil structure and therefore to erosion. (07, 22 stt)	I
(74)	Rfru sce03a Vegetation soil and basin fertility	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility (related to nutrient only). (07, 24 stt)	I
(75)	Rfru sce03b Vegetation soil and assume fertility correspond to nutrient	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility (with an assumption related to nutrient only). (07, 22 stt)	I
(76)	Rfru sce04a Vegetation soil basin fertility and organic matter	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility (related to nutrient and organic matter). (07, 24	I

		stt)	
(77)	Rfru sce04b Vegetation soil assume fertility correspond to nutrient and organic matter	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility (with an assumption related to nutrient and organic matter). (07, 22 stt)	I
(78)	Rfru sce05a Vegetation soil and assume fertility equals nutrient plus organic matter	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility, calculated in a different way (with an assumption related to nutrient + organic matter). (07, 22 stt)	I
(79)	Rfru sce05b Vegetation soil and assume fertility correspond nutrient plus organic matter	Vegetation is related to soil structure and therefore to erosion; soil has nutrient and fertility, calculated in a different way (with an assumption related to nutrient + organic matter). (07, 22 stt)	I
(80)	Rfru sce06a Assume fertility (correspond to nutrient) determines resource inflow	Soil fertility (nutrient) is considered the main resource for agriculture (cattle). Vegetation and erosion may affect the resource inflow and therefore the economic activity. (07, 63 stt)	VI, IV, III
(81)	Rfru sce06b Assume fertility (equals to nutrient plus organic matter) determines resource inflow	Soil fertility (nutrient + organic matter) is considered the main resource for agriculture (cattle). Vegetation and erosion may affect the resource inflow and therefore the economic activity. (07, 63 stt)	VI, IV, III
(82)	Rfru sce07a Assume fertility (influenced by manure) determines resource inflow	Vegetation and erosion may affect the resource inflow and therefore the economic activity. Soil fertility (nutrient + organic matter) is considered the main resource for agriculture (cattle). Manure is used to improve soil fertility (03, 18 stt)	VI, XII, IV, III
(83)	Rfru sce07b Assume manure determines resource inflow	Vegetation and erosion may affect the resource inflow and therefore the economic activity. Soil fertility (nutrient + organic matter) is considered the main resource for agriculture (cattle). Manure is used to improve soil fertility. (09, 18 stt)	VI, XII, IV, III
(84)	Rfru sce08 Vegetation removed soil and stream	Vegetation is related to soil erosion; removed soil by erosion may affect stream / river parameters (amount of sediments, depth amount of water). (07, 22 stt)	I
(85)	Rfru sce09 Removed soil	Vegetation is related to soil erosion; removed soil by erosion may affect	I

	stream and biodiversity	stream / river parameters (amount of sediments, depth amount of water) and change conditions for vertebrate survival. (07, 22 stt)	
(86)	Rfru sce10 Removed soil stream and crop production	Water from stream is considered the main resource for agriculture (crop production). Due to erosion in the basin, sediment may reduce the amount of water and affect the economic activity. (07, 65 stt)	VI, IV, III
(87)	Rfru sce11 Assume fertility (correspond to nutrient) determines crop resource inflow	Soil fertility (dependent on nutrient) is taken as the main resource for crop production; erosion may decrease nutrient available and therefore decrease economic activity. (07, 67 stt)	VI, IV, III
(88)	Rfru sce12 crop Production influenced by nutrient and stream	Water from stream and soil fertility (nutrient) are considered the main resources for agriculture (crop production). Erosion may have a negative effect on both resources and may hamper economic activity. (07, 65 stt)	VI, IV, III
(89)	Rfru sce13 Crop production influenced by nutrient stream and biodiversty	Water from stream and soil fertility (nutrient) are considered the main resources for agriculture (crop production). Erosion may have a negative effect on both resources and hamper economic activity; the simulation also includes the effects on biodiversity. (07, 65 stt)	VI, IV, III

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.7 Semi-urban Riacho Fundo model (Riacho Fundo case study, Brazil)

#	Scenario	Summary of simulations	Perspectives
(90)	Rfsu sce01a Urbanization and soil aggregation	Urbanization is associated to soil particles aggregation, which is the basis for a set of changes, explored in other simulations. (03, 09stt)	IV
(91)	Rfsu sce01b Urbanization decreasing and aggregation	Urbanization is associated to soil particles aggregation, which is the basis for a set of changes, explored in other simulations. (01, 07 stt)	IV
(92)	Rfsu sce01c Urbanization increasing and aggregation	Urbanization is associated to soil particles aggregation, which is the basis for a set of changes, explored in other simulations. (01, 07 stt)	IV

(93)	Rfsu sce02a Textile industry only	The basic mechanism of economic activity applied to textile industry. (03, 08 stt)	VI
(94)	Rfsu sce02b Food industry only	The basic mechanism of economic activity applied to the food industry. (03, 08 stt)	VI
(95)	Rfsu sce03a Semi urban erosion only	Urbanization changes soil particle aggregation and may be related to erosion. (05, 13 stt)	IV
(96)	Rfsu sce03b Infiltration only	Urbanization changes soil particle aggregation and may be related to erosion. (05, 26 stt)	IV
(97)	Rfsu sce04a River and removed soil	Effects of urbanization may affect soil erosion, and removed soil become sediments and affect parameters of the river (depth, amount of water). (05, 13 stt)	IV
(98)	Rfsu sce04b Springs and removed soil focus on erosion	Urbanization may lead to the disappearance of springs in two ways, one of them is the influence of erosion. (05, 13stt)	IV
(99)	Rfsu sce04c Springs and focus on infiltration aggregation decreasing	Urbanization may lead to the disappearance of springs in two ways, the other way is the influence of underground water. (09, 24 stt)	
(100)	Rfsu sce04d Springs and focus on infiltration aggregation increasing	Urbanization may lead to the disappearance of springs in two ways, the other way is the influence of underground water. The increasing level of aggregation eventually stop erosion and reduce the danger for the springs. (01, 27 stt)	IV
(101)	Rfsu sce05a Underground supplies water to textile industry	Underground water is the main resource used by textile industry, and urbanization has effects on the level of soil aggregation that may hamper the economic activity. (01, 91 stt)	VI, IV, III
(102)	Rfsu sce05b Underground supplies water to textile and river pollution	Underground water is the main resource used by textile industry, and urbanization has effects on the level of soil aggregation, that may improve the economic activity and therefore increase pollution. (01, 24 stt)	VI, IV, III
(103)	Rfsu sce06a River supplies water to food industry	Urbanization may affect erosion, which in turn may affect river parameters; river water is used as resource for industrial production. (05, 37 stt)	

(104)	Rfsu sce06b River supplies water food industry and river pollution	Urbanization may affect erosion, which in turn may affect river parameters; river water is used as resource for industrial production, and the effluents pollute the river water. (05, 37 stt)	
(105)	Rfsu sce07a Springs focus infiltration and food industry	Water from springs are used as resource for food industry; however, urbanization may hamper the infiltration process, springs disappear and economic activity decrease. (01, 49 stt)	VI, IV, III
(106)	Rfsu sce07b Springs focus erosion and food industry	Water from springs are used as resource for food industry; however, urbanization may lead to erosion, springs disappear and economic activity decrease. (05, 37 stt)	VI, IV, III

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.8 Urban Riacho Fundo (Riacho Fundo case study, Brazil)

#	Scenario	Summary of the simulations	Perspectives
(107)	Rfur sce01a Drainage zero steady	Heavy rain in urban areas, in a short period of time, may become uncontrolled flow of water, that cause economic damage and floods, if there is no engineered drainage system. (01, 03 stt)	II, VI
(108)	Rfur sce01b Drainage increasing	Heavy rain in urban areas, in a short period of time, may become a uncontrolled flow of water, that cause economic damage and cause floods; but if there is an engineered drainage system, these unsustainable conditions may be fixed. (01, 07 stt)	XII, VI
(109)	Rfur sce02 Services and garbage	The basic mechanism of economic activities applied to services / garages, which produce garbage and create jobs. (01, 51 stt)	VI
(110)	Rfur sce03a No drainage and transported garbage	Heavy rain may become uncontrolled flow of water, that cause economic damage and floods; economic activity produces garbage, that may be carried by the uncontrolled flow. (03, 21 stt)	II, VI
(111)	Rfur sce03b Drainage and transported garbage	Heavy rain may become uncontrolled flow of water, that cause economic damage and floods; economic activity produces garbage,	XII, VI

		that may be carried by the uncontrolled flow. Human-made drainage system may revert this situation and reduces the damage. (03, 85 stt)	
(112)	Rfur sce04a No drainage transported garbage and well being	Uncontrolled flow of water causes economic damage and floods; uncontrolled flow may carry garbage produced by economic activities, and this is a negative factor on human well being. (03, 09 stt)	XIII, II, VI
(113)	Rfur sce04b Drainage transported garbage and well being	Uncontrolled flow of water causes economic damage and floods; uncontrolled flow may carry garbage produced by economic activities, and this is a negative factor on human well being. Urban engineered drainage system may control this situation. (03, 177 stt)	XII, XIII, VI
(114)	Rfur sce05a Mosquitos growth only	Biological process of population growth of mosquitos. (01, 03 stt)	I
(115)	Rfur sce05b No drainage flooded areas and mosquitos	Heavy rain in urban areasmay become uncontrolled flow of water, that cause economic damage and cause floods, if there is no engineered drainage system. Mosquitos are stimulated in such environment. (01, 06 stt)	II, VI
(116)	Rfur sce05c Drainage flooded areas and mosquitos	Heavy rain in urban areas may become a uncontrolled flow of water, that cause economic damage and cause floods, Mosquitos are stimulated in such environment, but an engineered drainage system may control mosquitos population size. (01, 43 stt)	XII, VI
(117)	Rfur sce06a No drainage flooded areas and water related diseases	Heavy rain in urban areas may become a uncontrolled flow of water, that cause economic damage and cause floods, if there is no engineered drainage system. Pathogens develop well in such environment. (01, 02 stt)	II, VI, XIII
(118)	Rfur sce06b Drainage flooded areas and water related diseases	Heavy rain in urban areas may become a uncontrolled flow of water, that cause economic damage and cause floods, if there is no engineered drainage system. Pathogens develop well in such environment. Urban engineered drainage system may control this	XII, XIII, VI

		situation. (01, 07 stt)	
(119)	Rfur sce06c No drainage floods pathogens and mosquitos	Heavy rain in urban areas may become a uncontrolled flow of water, that cause economic damage and cause floods, if there is no engineered drainage system. Pathogens and mosquitos develop well in such environment. (01, 06 stt)	II, XIII, VI
(120)	Rfur sce06d Drainage floods pathogens and mosquitos	Heavy rain in urban areas may become a uncontrolled flow of water, that cause economic damage and cause floods, if there is no engineered drainage system. Pathogens and mosquitos develop well in such environment. Urban engineered drainage system may control this situation. (01, 43 stt)	XII, XIII, VI
(121)	Rfur sce07a No drainage diseases and well being	Uncontrolled flow of water causes economic damage and cause floods, if there is no engineered drainage system. Pathogens develop well in flooded areas, and represent a negative factor for human well being. (03, 13 stt)	II, XIV, XIII, VI
(122)	Rfur sce07b Drainage diseases and well being	Uncontrolled flow of water causes economic damages and floods. Pathogens develop well in flooded areas and represent a negative factor for human well being. An engineered drainage system reduce pathogens and increase human quality of life. (01, 15 stt)	XII, XIV, XIII, VI
(123)	Rfur sce08a No drainage garbage mosquitos diseases and well being	Heavy rain in urban areas may become uncontrolled flow of water, that cause economic damage and floods, if there is no engineered drainage system. Uncontrolled water carries garbage, pathogens and mosquitos develop well in flooded areas. These are negative factors for human well being and reduce the quality of life. (03, 27 stt)	II, XIV, XIII, VI
(124)	Rfur sce08b Drainage garbarge mosquitos diseases and well being	Heavy rain in urban areas, become uncontrolled flow of water, that cause economic damage and floods. Pathogens and mosquitos develop well in flooded areas. Urban engineered drainage system changes this situation and improve quality of life. (01, 333 stt)	XII, XIV, XIII, VI

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.9 River Mesta model (River Mesta case study, Bulgaria)

#	Scenario	Original model	Perspective
(125)	Rm sce01a Dissolved oxygen only	River parameters (heat, temperature, diffusion rate, flow velocity, aeration rate) influence concentration of dissolved oxygen. (03, 11 stt)	I
(126)	Rm sce01b Aeration and diffusion unequal	River parameters (heat, temperature, diffusion rate, flow velocity, aeration rate) influence concentration of dissolved oxygen. (03, 06 stt)	I
(127)	Rm sce02aa Water abstraction increases and sun heat decreases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 26 stt)	IV
(128)	Rm sce02ab Water abstraction constant increases and sun heat constant decreases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 15 stt)	IV
(129)	Rm sce02ba Water abstraction decreases and sun heat increases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 37 stt)	IV
(130)	Rm sce02bb Water abstraction constant decreases and sun heat constant increases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 15 stt)	IV
(131)	Rm sce02ca Water abstraction decreases and sun heat decreases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 65 stt)	IV
(132)	Rm sce02cb Water abstraction constant decreases and sun heat constant decreases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 20 stt)	IV
(133)	Rm sce02da Water abstraction increases and sun heat increases	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 20 stt)	IV
(134)	Rm sce02db Water abstraction constant increases and sun heat	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (05, 20 stt)	IV

	constant increases		
(135)	Rm sce02ea Water abstraction steady and sun heat steady	Agents water abstractor and sun influence river water parameters, according to specific initial conditions. (03, 11 stt)	IV
(136)	Rm sce03a Pollution increases	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (01, 17 stt)	IV
(137)	Rm sce03b Solar radiation increases day time	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (03, 58 stt)	IV
(138)	Rm sce03c Solar radiation decreases the night	Agents (water abstractor, erosion, sun and polluter) influence river water parameters, according to specific initial conditions. (01, 19 stt)	IV
(139)	Rm sce03da Water abstraction increases	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (01, 03 stt)	IV
(140)	Rm sce03db Water abstraction decreases	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (01, 20 stt)	IV
(141)	Rm sce03ea Erosion increases	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (01, 14 stt)	IV
(142)	Rm sce03eb Erosion decreases	Agents (water abstractor, erosion, sun and polluter) and physical and biological factors influence river water parameters, according to specific initial conditions. (01, 71 stt)	IV

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.10 Stakeholder participation (River Kamp case study, Austria)

#	Scenario	Summary of the simulations	Perspectives
(143)	Sp sce01a Catastrophic effects only	A catastrophic event destroys a urban area. (01, 06 stt)	II, XI

(144)	Sp sce01b Emergency activities in catastrophes	A catastrophic event causes destruction in urban area. Emergency actions taken by the government reduces its effects. (01, 07 stt)	XI
(145)	Sp sce01c Catastrophe and emergency activities	Fear of catastrophes motivates the public to put pressure on the government for emergencial actions against the consequences of the catastrophic events. (03, 07 stt)	XI
(146)	Sp sce02a Centralization decentralization and participation medium	Legistation in favour and against centralization may increase public involvement and participation of stakeholders in the decision making process, according to specific initial conditions. (07, 29 stt)	IX, X
(147)	Sp sce02b Centralization decentralization and participation low	Legistation in favour and against centralization may increase public involvement and participation of stakeholders in the decision making process, according to specific initial conditions. (07, 41 stt)	IX, X
(148)	Sp sce02c Decentralization greater than centralization and participation	Legistation in favour and against centralization may increase public involvement and participation of stakeholders in the decision making process, according to specific initial conditions. (03, 12 stt)	IX, X
(149)	Sp sce02d Decentralization smaller centralization and participation	Legistation in favour and against centralization may increase public involvement and participation of stakeholders in the decision making process, according to specific initial conditions. (03, 06 stt)	IX, X
(150)	Sp sce03a Agent education only	Investment in education improves education level of the community (01, 03 stt)	VII
(151)	Sp sce03b Agent education leads to participation	Investment in education improves education level of the community (01, 07 stt)	VII
(152)	Sp sce03c Agent education leads to stakeholder participation	Investment in education improves education level of the community, access to decision making and information increase stakeholder participation. (01, 07 stt)	X, VII
(153)	Sp sce03d Agent education decreasing and stakeholder participation	Less investment in education reduces education level of the community, access to decision making and information may decrease stakeholder participation. (01, 08 stt)	X, VII

(154)	Sp sce03e Stakeholder participation increase quality of the plans	Investment in education improves que education level of the community, access to decision making and information increase stakeholder participation. As a consequence, the quality of sustainability plans increases. (01, 19 stt)	X, VII
(155)	Sp sce03f Less stakeholder participation decreases quality of the plans	Less investment in education reduces education level of the community, access to decision making and information may decrease stakeholder participation. As a consequence, the quality of sustainability plans decreases. (01, 51 stt)	X, VII
(156)	Sp sce04a Technological solutions	Involvement of scientific community produces technological solutions, specific scenario (01, 03 stt)	VIII
(157)	Sp sce04b Technological solutions decreasing	Involvement of scientific community produces technological solutions, according to specific initial conditions. (01, 03 stt)	VIII
(158)	Sp sce04c Technological solutions increasing applied to planning	Involvement of scientific community produces technological solutions, that can be applied to planning sustainability, according to specific initial conditions. (01, 07 stt)	X, VIII
(159)	Sp sce04d Technological solutions decreasing applied to planning	Involvement of scientific community produces technological solutions, that can be applied to planning sustainability, according to specific initial conditions. (01, 09 stt)	X, VIII
(160)	Sp sce05a Planners qualification increasing	Investment in qualification results in better qualified planners. (01, 03 stt)	VII
(161)	Sp sce05b Planners qualification decreasing	Less investment in qualification results in less qualified planners. (01, 03 stt)	VII
(162)	Sp sce05c Planners qualification increasing and the plans	Investment in qualification results in better qualified planners, who are capable to produce better plans. (01, 07 stt)	XI, VII
(163)	Sp sce05d Planners qualification decreasing and the plans	Less investment in qualification results in less qualified planners, who are not able to produce good plans. (01, 09 stt)	XI, VII
(164)	Sp sce06a	Agents investing in planner	VII, VIII

	Agents influence increase quality sustainability plans	qualification and in scientific development produce better quality sustainability plans. (01, 12 stt)	
(165)	Sp sce06b Agents influence decrease quality sustainability plans	Less investments in planner qualification and in scientific development produce worse quality sustainability plans. (01, 27 stt)	VII, VIII
(166)	Sp sce06c Agents increase planners quality and reduce technology	Agents investing in planner qualification and less investment in scientific development influence the quality sustainability plans. (03, 25 stt)	VII, VIII
(167)	Sp sce06d Agents decrease quality plans and increase technology	Agents investing less in planner qualification and more investment in scientific development influence the quality sustainability plans. (03, 25 stt)	VII, VIII
(168)	Sp sce07a Agents and stakeholder influence quality of the plans	Agents investing in planner qualification and in scientific development and stakeholder participation produces better quality sustainability plans. (03, 39 stt)	VII, VIII, IX, X, XI
(169)	Sp sce07b Agents and stakeholder decreasing influence quality plans	Agents investing less in planner qualification and in scientific development and less stakeholder participation produces worse quality sustainability plans. (03, 84 stt)	VII, VIII, IX, X, XI
(170)	Sp sce07c Stakeholder influence quality of plans with assumptions	Agents investing in planner qualification and in scientific development and stakeholder participation produce better quality sustainability plans, with the use of some assumptions. (03, 39 stt)	VII, VIII, IX, X, XI
(171)	Sp sce08a Private interest plans increasing	Agent representing private interest produces a group of pressure who produces an increasingly biased plan for sustainability. (01, 06 stt)	XI
(172)	Sp sce08b Private interest plans decreasing	Agent representing private interest produces a group of pressure who produces a less biased plan for sustainability. (01, 06 stt)	XI
(173)	Sp sce09a Plans and group of interest influence government actions	Agents investing in planner qualification and in scientific development, stakeholder participation and group of pressure influence the quality of sustainability plans. (09, 69 stt)	VII, VIII, IX, X, XI
(174)	Sp sce09b Plans and groups steady influence government actions	Agents investing in planner qualification and in scientific development, stakeholder participation and steady effort from	VII, VIII, IX, X, XI

		group of pressure influence the quality of sustainability plans. (03, 63 stt)	
(175)	Sp sce09c Planners and group of interest steady and government actions	Agent investing in scientific development and stakeholder participation and steady planner qualification agent and steady effort from group of pressure influence the quality of sustainability plans. (03, 33 stt)	VII, VIII, IX, X, XI
(176)	Sp sce10a Restoration increasing	Restoration process improves environmental conditions and ecological integrity of the basin. (01, 05 stt)	XII
(177)	Sp sce10b Restoration decreasing	Decreasing restoration results in worse environmental conditions and less ecological integrity. (01, 05 stt)	XII
(178)	Sp sce11a Influences on government and river restoration decrease	Stakeholder participation is decreasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure determine the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on restoration process. (03, 33 stt)	VII, VIII, IX, X, XI, XII
(179)	Sp sce11b Influences on government and river restoration increase	Stakeholder participation is increasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influence determine the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on restoration process. (03, 33 stt)	VII, VIII, IX, X, XI, XII
(180)	Sp sce12a Human well being decreasing and then increasing	Human well being is assessed in terms of a compensation mechanism involving positive and negative factors. (01, 06 stt)	XIV
(181)	Sp sce12b Human well being only increasing	Human well being is assessed in terms of a compensation mechanism involving positive and negative factors, with an assumption. (01, 05 stt)	XIV
(182)	Sp sce13a Influences on government and well being decreasing	Stakeholder participation is decreasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influencing the quality of sustainability plans and	VII, VIII, IX, X, XI, XII, XIV

		further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being. (03, 33 stt)	
(183)	Sp sce13b Influences on government and well being increasing	Stakeholder participation is increasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influencing the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being. (03, 33 stt)	VII, VIII, IX, X, XI, XII, XIV
(184)	Sp sce14a Government well being and ecological integrity decreasing	Stakeholder participation is decreasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influencing the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being and on restoration of the river basin. (03, 90 stt)	VII, VIII, IX, X, XI, XII, XIV
(185)	Sp sce14b Government well being and ecological integrity decreasing	Stakeholder participation is decreasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influencing the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being and on restoration of the river basin, under specific conditions. (03, 30 stt)	VII, VIII, IX, X, XI, XII, XIV
(186)	Sp sce14c Government well being and ecological integrity increasing	Stakeholder participation is increasing, agents investing in scientific development and planner qualification are steady, and steady group of pressure influencing the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being and on restoration of the river basin. (03, 90 stt)	VII, VIII, IX, X, XI, XII, XIV
(187)	Sp sce14d Government well being and ecological integrity	Stakeholder participation is increasing, agents investing in scientific development and planner qualification are steady, and steady	VII, VIII, IX, X, XI, XII, XIV

	increasing	group of pressure influencing the quality of sustainability plans and further the amounf of sustainable and non-sustainable governmental actions on positive factors of human well being and on restoration of the river basin under specific conditions. (03, 84 stt)	

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.3.11 Salmon and Bream model (Rivers Trent and Great Ouse case study, England)

#	Scenario	Summary of the simulations	Perspectives
(188)	Uk sce01a Single life stage habitat quality declining	As habitat quality decline, it affects number of surviving individuals and population potential. (01, 16 stt)	I
(189)	Uk sce01b Single life stage habitat quality increase	As habitat quality increase, it affects number of surviving individuals and population potential. (01, 16 stt)	I
(190)	Uk sce02a Single life stage recruitment increase	As habitat quality is steady and recruited increase, number of surviving individuals and potential population are affected. (01, 16 stt)	I
(191)	Uk sce02b Single life stage recruitment declining	As habitat quality is steady and recruited decrease, number of surviving individuals and potential population are affected. (01, 16 stt)	I
(192)	Uk sce03a Single life stage both decrease	As both habitat quality and recruited decrease, they affect number of surviving individuals and potential population. (01, 11 stt)	I
(193)	Uk sce03b Single life stage both increase	As both habitat quality and recruited increase, they affect number of surviving individuals and potential population. (01, 11 stt)	I
(194)	Uk sce04a Single life stage recruitment zero increase habitat decrease	As recruited increase and habitat quality decrease, they affect number of surviving individuals and potential population. (01, 78 stt)	I
(195)	Uk sce04b Single life stage recruitment increase habitat steady	As recruited increase and habitat quality is steady, they affect number of surviving individuals and potential population. (01, 10 stt)	I

(196)	Uk sce04c Single life stage recruitment increase habitat decrease	As recruited increases and habitat quality decreases, they affect number of surviving individuals and potential population. (01, 11 stt)	I
(197)	Uk sce05 Rehabilitation	Agent environmental manager rehabilitates a river that is spawning habitat for salmon. (01, 05 stt)	XII
(198)	Uk sce06 Stocking	Agent manager and recruited individuals from egg populations increase the number of juveniles. (01, 13 stt)	XII
(199)	Uk sce07 Sedimentation and rehabilitation	Agent environmental manager rehabilitates upland river and improve the quality of spawning gravels. (01, 05 stt)	XII
(200)	Uk sce08 Sub adult bream scenario	Channelization influences subadult and adult populations. (01, 46 stt)	IV
(201)	Uk sce09 Juvenile salmon scenario	Juvenile populations inhabit upland river, and in upland catchment agent manager rehabilitates the basin and agent water industry changes the environment; juveniles recruits into smolt population. (01, 46 stt)	XII
(202)	Uk sce10 Trent connectivity rehabilitation (no stocking no immigration)	Eggs recruit into juvenile population; this one recruits into smolt population, and individuals from this population recruits into adult population. Environmental manager enhance connectivity. (01, 05 stt)	XII

The two numbers between brackets represent the number of initial states, and the total number of estates produced in the simulation.

5.4 Perspectives and simulations in details

The following table shows how all the simulations included in the Library can be used to the illustrated insteresting issues in each thematic perspective. Of course, the same simulation can be allocated to more than one perpective.

Perspectives	Simulations
(I) Natural systems	{Aw01a-d; Aw02a-c; Aw06}; {Dd04; Dd05; Dd06; Dd07a-b; Dd08; Dd09; Dd10a-b}; {Rfru01a-b; Rfru02; Rfru03a-b; Rfru04a-b; Rfru05a-b; Rfru08; Rfru09}; {Rfur05a}; {Rm01a-c}; {Uk01a-b; Uk02a-b; Uk03a-b; Uk04a-c}
(II) Natural	{Rfur01a; Rfur03a; Rfur04a; Rfur05b; Rfur06a; Rfur06c;

disasters	Rfur07a; Rfur08a}; {Sp01a; Sp01b-c}
(III) Human explores natural resources	{Aw03; Aw04; Aw05a-b; Aw08a; Aw09a; Aw09b; Aw09c}; {D01; D02; D03; D04; D05}; {E03a}; {Rfru06a-b; Rfru07a-b; Rfru10; Rfru11; Rfru12; Rfru13}; {Rfsu05a-b; Rfsu06a-b; Rfsu07a-b}
(IV) Environmental effects of human activities (in interaction with natural factors)	{Aw03; Aw04; Aw05a-b; Aw07a-g; Aw08b-f; Aw10a-c}; {D01}; {Dd01a-c; Dd02a-b; Dd03a-c; Dd12; Dd13; Dd14}; {E01a-c; E02a-b; E03a-b}; {Gw02; Gw03}; {Rfru06a-b; Rfru07a-b; Rfru10; Rfru11; Rfru12; Rfru13}; {Rfsu01a-c; Rfsu03a-b; Rfsu04a-c; Rfsu05a-b; Rfsu06a-b; Rfsu07a-b}; {Rm02aa-ea; Rm03a-eb}; {Uk08}
(V) Energy	{Aw09a; Aw09b; Aw09c; Aw10a-c}; {Gw01; Gw02; Gw03}
(VI) Economy	{Aw09c; Aw10a-c}; {D02; D03; D04; D05} {E01a-c; E02a-b; E03a-b}; {Gw01; Gw02; Gw03}; {Rfru06a-b; Rfru07a-b; Rfru10; Rfru11; Rfru12; Rfru13}; {Rfsu02a-b; Rfsu05a-b; Rfsu06a-b; Rfsu07a-b}; {Rfur01a; Rfur01b; Rfur02; Rfur03a-b; Rfur04a-b; Rfur04b-c; Rfur05b-c; Rfur06a-d; Rfur06c; Rfur07a-b; Rfur08a-b}
(VII) Education and trainning	{Sp03a-b; Sp03c-f; Sp05a-b; Sp05c-d; Sp06a-d; Sp07a-c; Sp09a-c; Sp11a-b; Sp13a-b; Sp14a-d}
(VIII) Science and Technology	{Sp04a-b; Sp04c-d; Sp06a-d; Sp07a-c; Sp09a-c; Sp11a-b; Sp13a-b; Sp14a-d}
(IX) Legislation	{Sp02a-c; Sp07a-c; Sp09a-c; Sp11a-b; Sp13a-b; Sp14a-d}
(X) Stakeholder participation	{Sp02a-c; Sp03c-f; Sp07a-c; Sp09a-c; Sp11a-b; Sp13a-b; Sp14a-d}
(XI) Governmental plans and activities	{Sp01b-c; Sp04c-d; Sp05c-d; Sp07a-c; Sp08a-b; Sp09a-c; Sp11a-b; Sp13a-b; Sp14a-d}
(XII) Management actions for sustainability	{Rfru07a-b; Rfur01b; Rfur03b; Rfur04b; Rfur05c; Rfur06b; Rfur06d; Rfur07b}; {Sp10a-b; Sp11a-b; Sp13a-b; Sp14a-d}; {Uk05; Uk06; Uk07; Uk09; Uk10}
(XIII) Human health	{Dd15; Dd16a-c}; {Gw03}; {Rfur06a-d; Rfur07a-b; Rfur08a-b}
(XIV) Human well being	{D05}; {Rfur04a-b; Rfur07a-b; Rfur08a-b}; {Sp12a-b; Sp13a-b; Sp14a-d};

Below each perspective is illustrated with some representative simulations.

5.4.1 I – Natural systems perspective

The natural systems perspective includes a number of simulations. A common feature to all of them is the absence of human intervention. This perspective explores rivers, plants, animals, food webs, soil and nutrients and other elements. Some examples are presented below.

On of the simplest representations of a river in the Library is the simulation Aw sce02a. The causal model shows that the amount of water in a segment of the river is calculated by the balance between flow in and flow out.

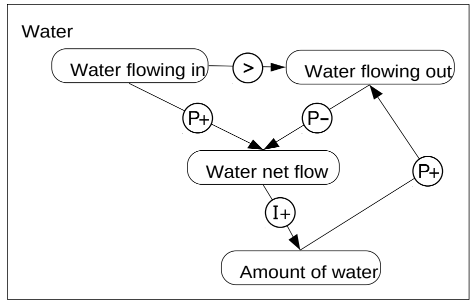

Figure 4. Causal model obtained in simulation Aw sce02a Water in the river increasing: causal model in state 1.

In Figure 5, physical factors influencing the dissolved oxygen concentration are causally arranged.

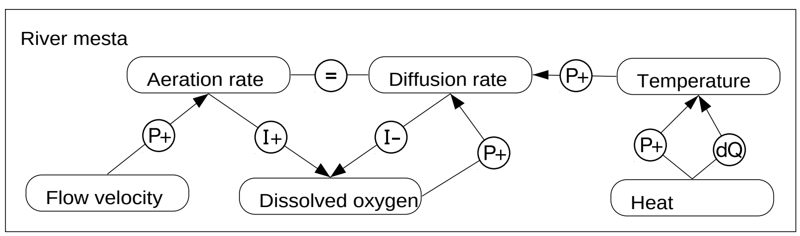

Figure 5. Causal model obtained in simulation Rm01a Dissolved oxygen only, state 1.

The dynamics of regeneration and degradation of the vegetation and its relation to the erosion process are represented in Figure 6.

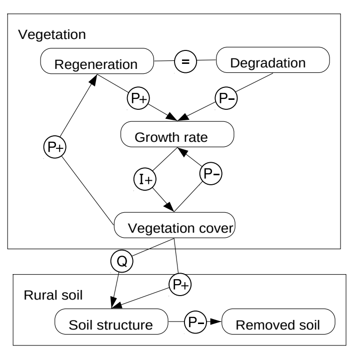

Figure 6. Causal model obtained in simulation Rfru02 Vegetation dynamics and soil, state 1.

A more complex causal model, showing the causal relations between four populations in a food web (diatoms, zooplankton, fish and birds), is presented in Figure 7.

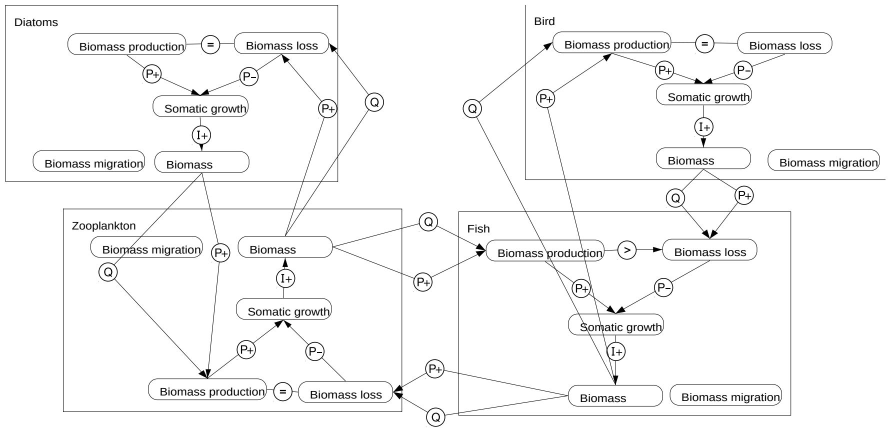

Figure 7. Causal model obtained in simulation Dd11 Diatoms, zooplankton, fish and birds, state 1.

5.4.2 II – Natural disasters perspective

The Library contains two representations of natural disasters: a general representation of this type of event, consisting of a combination of destruction, damages, emergency actions and fear of the catastrophe is presented in Figure 8. The second representation is for floods in urban areas, as found in the Urban Riacho Fundo model (Salles et al., 2007).

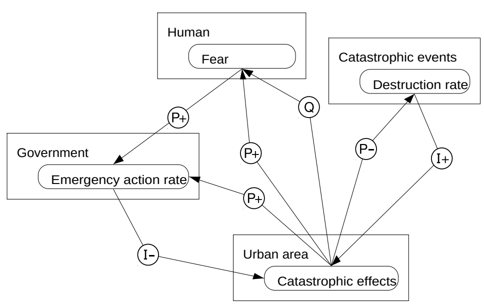

Figure 8. Causal model obtained in simulation Sp01c Catastrophe and emergency activities, state 1.

5.4.3 III – Human explores natural resources perspective

An interesting example of a simulation that combines exploitation of natural resources comes from the Deforestation model and is presented in Figure 9.

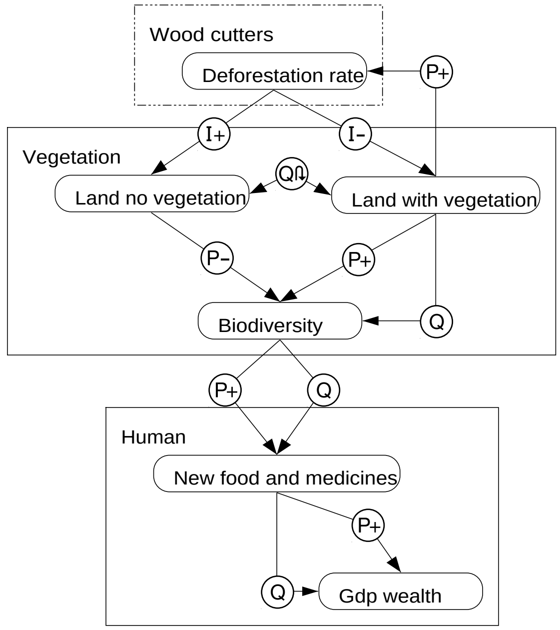

Figure 9. Causal model obtained in simulation D02 Deforestation impacts on new food and medicines, state 1.

5.4.4 IV – Environmental effects of human activities (in interaction with natural factors) perspective

The Library is full of simulations showing different types of effects caused by human activities. Two causal models were select to illustrate this perspective: the effects of the urbanization process on erosion and land integrity (Figure 10) and the effects of water abstraction on physical factors or the river and on two types of fishes (Figure 11).

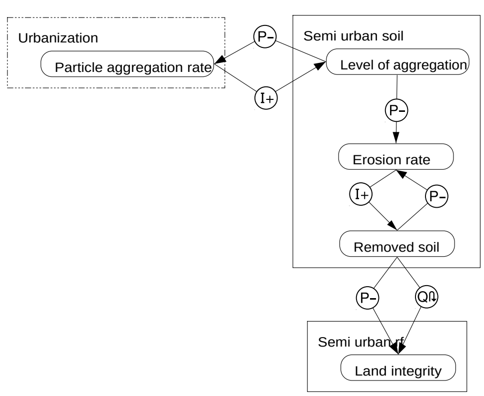

Figure 10. Causal model obtained in simulation Rfsu03a Semi urban erosion only, state 1.

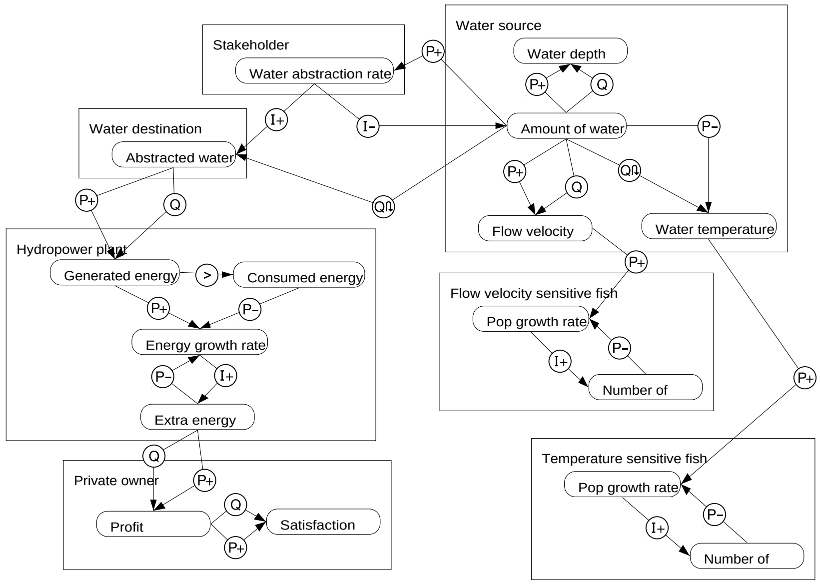

Figure 11. Causal model obtained in simulation Aw10c.

5.4.5 V – Energy perspective

Despite the great importance of energy for sustainability, this topic is not abundant in the Library. Figure 12 shows the mechanism of extra energy generation, a surplus that could be further used for commercial use.

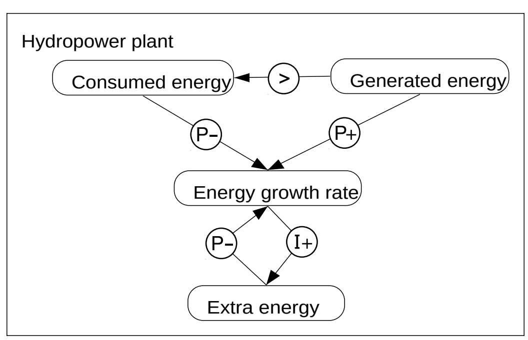

Figure 12. Causal model obtained in simulation Aw9a Energy production only, state 1.

Still related to the energy issue, Figure 13 shows how the use of petrolleum, controlled by the global market, may drive industrial activities and produce pollutants that may cause global warming.

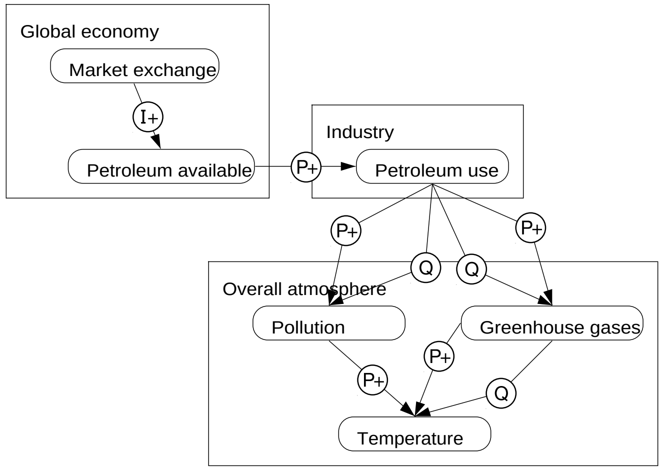

Figure 13. Causal model obtained in simulation Gw02 Petroleum and atmosphere, state 1.

5.4.6 VI – Economy perspective

A large number of simulations explore economic aspects of sustainability. Two causal models illustrate these simulations: the basic structure used in the Library for a generic representation of agriculture, industry and services (Figure 14) and the effects on GDP of agriculture, use of water resources and technological innovation exploring biodiversity (Figure 15).

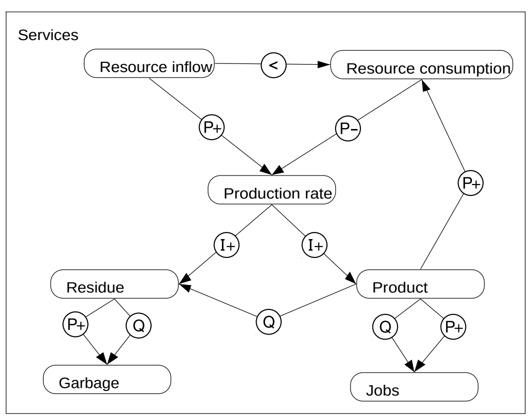

Figure 14. Causal model obtained in simulation Rfur02 Services, state 1.

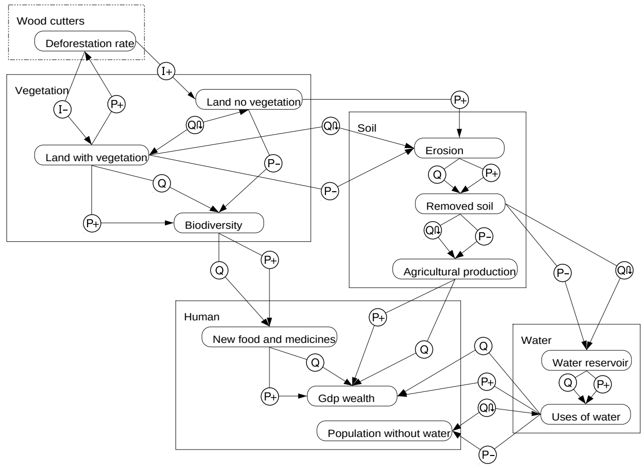

Figure 15. Causal model obtained in simulation D05 Deforestation impact on GDP, state 1.

5.4.7 VII – Education and trainning

Education and trainning are essential aspects of sustainability. In the Library these issues are related to the community inclusion in projects (Figure 15) and the qualification of planners.

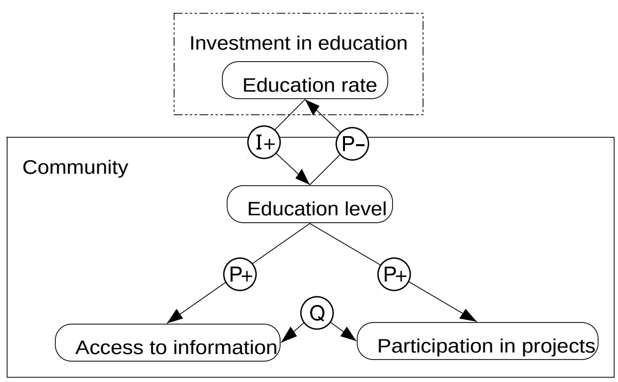

Figure 15. Causal model obtained in simulation Sp03b Agent education leads to participation, state 1.

5.4.8 VIII – Science and technology perspective

Scientific community is represented in the Library as the providers of technological solutions, that may solve sustainability problems. The causal model shown in Figure 16 illustrates this aspect of planning for sustainability.

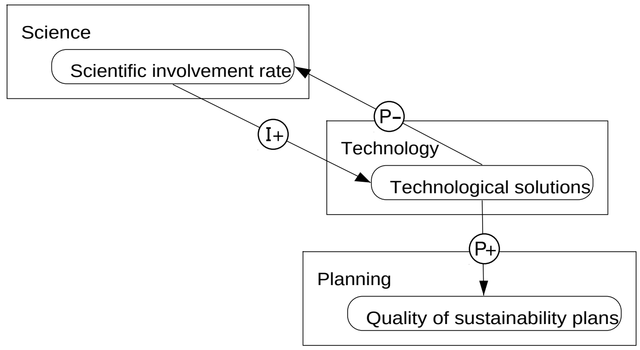

Figure 16. Causal model obtained in simulation Sp04c Technological solutions increasing applied to planning, state 1.

5.4.9 IX – Legislation perspective

Community in general and particularly stakeholder participation should be regulated by legislation. Two types of legislation are found; the one that decentralize power and give high value to the participation of the public, and the other that moves in the contrary direction and centralizes decision making processes. Figure 17 illustrates how these two types of laws that influence society.

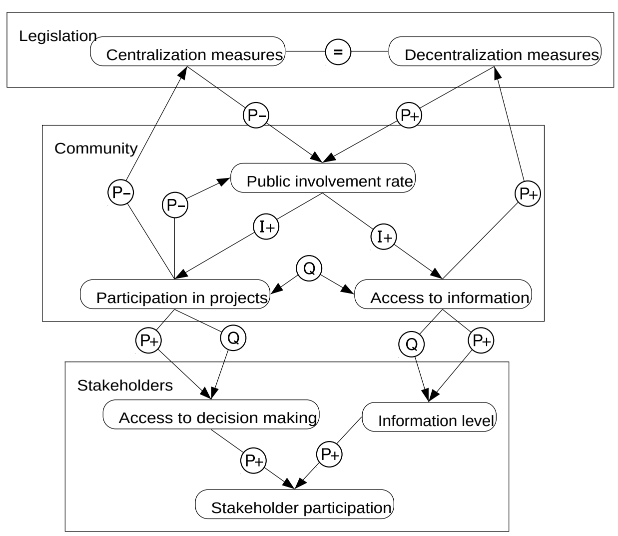

Figure 17. Causal model obtained in simulation Sp02a Centralization decentralization and participation medium, state 1.

5.4.10 X – Stakeholder participation perspective

Stakeholder participation is illustrated here by the importance of education for preparing high quality plans for sustainability (Figure 18).

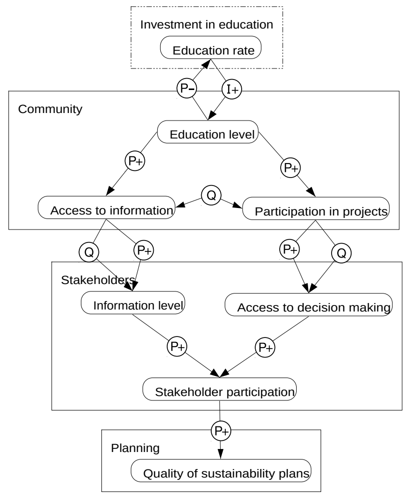

Figure 18. Causal model obtained in simulation Sp03e Stakeholder participation increase quality of the plans, state 1.

5.4.11 XI – Governmental plans and activities perspective

The government receives pressures from the whole society, and public policies in a way represent the results of these pressures. In the simulation models selected for this perspective, as shown in Figure 19, sustainable and non-sustainable governmental actions influence human well being and the ecological integrity in the basin.

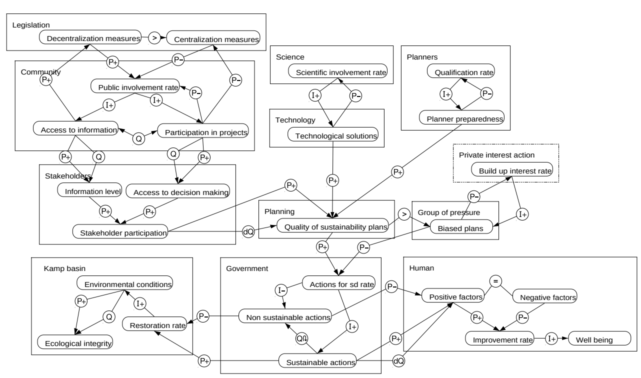

Figure 19. Causal model obtained in simulation Sp14d Government well being and ecological integrity increasing, state 1.

5.4.12 XII – Management actions for sustainability perspective

An expressive number of simulations address management actions for a sustainable world. Figure 20 shows fishery manager stocking the salmon population, in order to compensate a possible low number of juvenile recruited by means of introducing new individuals to the population.

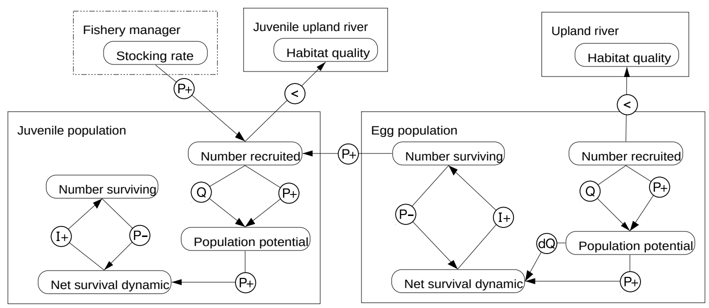

Figure 20. Causal model obtained in simulation Uk06 Stocking, state 1.

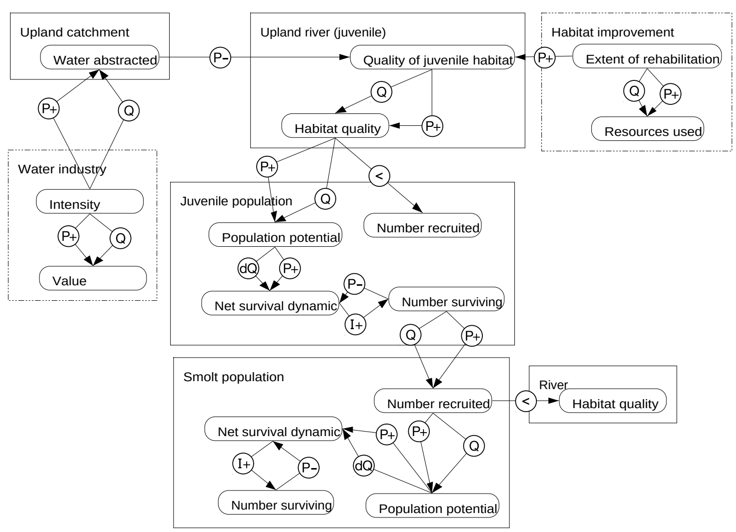

Figure 21. Causal model obtained in simulation Uk09 Juvenile salmon scenario, state 1.

5.4.13 XIII – Human health perspective

Pollution and water related-diseases are represented in the Library models. Figure 22 represents the effects of atmospheric pollution (indoor and outdoors) on respiratory diseases. Water related diseases are included in the Urban Riacho Fundo perspective.

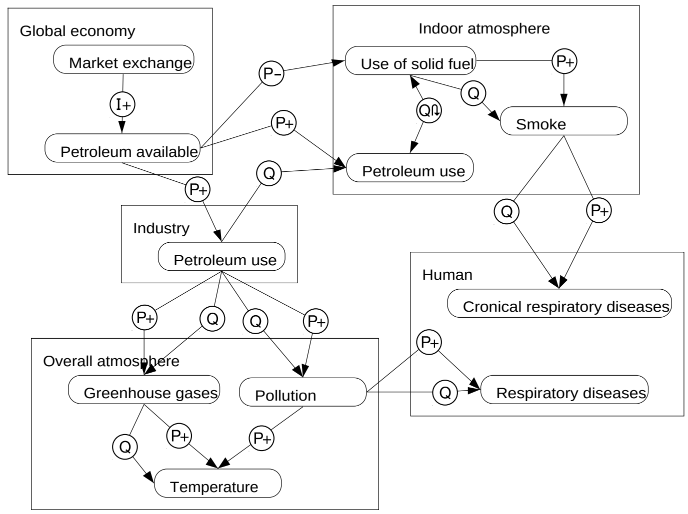

Figure 22. Causal model obtained in simulation Gw03 Solid fuel and global warming, state 1.

5.4.14 XIV – Human well being perspective

Human well being is represented in the Library by means of a balanced mechanism that combines generic 'positive and negative factors', as shown in Figure 23.

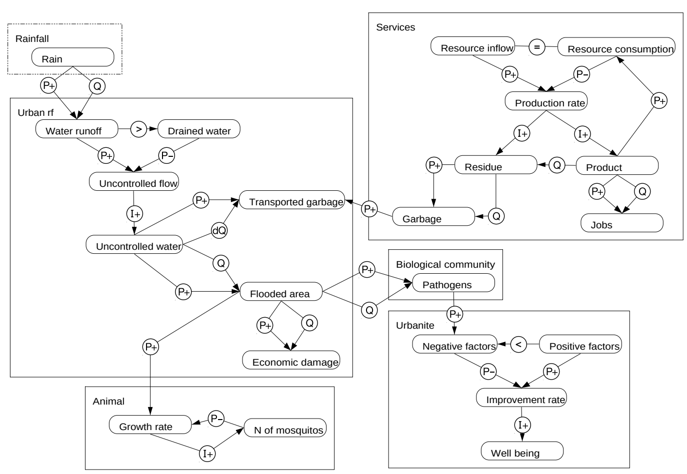

Figure 23. Causal model obtained in simulation Rfur08a No drainage garbage mosquitos diseases and well being, state 1.

6 DISCUSSION

This Deliverable describes the use of perspectives to organize a large library of model fragments in order to create sets of simulation models each addressing a class of sustainability issues. Two groups of perspectives (*case study-based* and *thematic-based perspectives*) are taken to represent different types of sustainability aspects, and a wide range of assumptions and applications of modelling elements were defined to implement the case study-based perspectives. The thematic-based perspectives are defined in terms of the knowledge encoded in the Library and the simulations are not automatically organized.

Assumptions were used when implementing the Library and represent a technical approach to defining perspectives. Accordingly, they were valuable to define the case study-based perspectives (Natural, Rural, Semi-urban, Urban, Natural resources exploitation, Natural environment rehabilitation and Social). The use of assumptions for reasoning with multiple models has a long tradition in Qualitative Reasoning (Bobrow, 1984). de Kleer and Brown (1984) point out the importance of making modelling assumptions explicit and of changing them during problem solving. A number of authors have been working on developing algorithms for automatically selecting or changing models according to certain assumptions. For example, Addanki *et al*. (1991) represent domain knowledge as graph of models and change assumptions to move from one model to the other; and Liu and Farley (1991) took a different approach to automate task-driven reasoning about physical systems using multiple perspectives. Falkenhainer and Forbus (1991) developed *compositional modelling*, a technique to decompose domain knowledge into model fragments, and implemented an algorithm for model composition given a domain theory, a structural description of the system and a query to be answered. Rickel and Porter (1997), using the compositional modelling approach, developed an algorithm to build the simplest adequate model from building blocks (single variables and influences) for answering prediction questions within a certain time scale, and tested it in the domain of botany and plant physiology.

Differently from these previous approaches, the work described here addresses sustainability using no numerical information or mathematical functions to define perspectives or to implement assumptions, only qualitative representations of concepts. Garp3's representational apparatus and algorithm are explored to capture ecological knowledge and to create alternative models according to the perspective taken. In this section, the examples describe the implementation of three perspectives for the Riacho Fundo case study (Rural, Semi-urban and Urban). For details, consult Salles *et al*. (2007).

The first element used to create a simulation model taking a certain perspective are the entities, such as ‘Rural rf’, ‘Semi-urban rf’ and‘Urban rf’. Increasing levels of complexity can be further obtained by means of the inclusion of new entities in the system structure. In fact, control over entities and quantities introduced in the model is an important and quite effective use of simplifying assumptions to implement perpectives. Considering that: each entity can be associated to a number of quantities; each quantity can be modelled using different quantity spaces; and each qualitative value represents a qualitative state of the entity, the choice of entities, quantities and quantity space defines specific vocabulary for a certain perspective. For example, different types of economic activities can be associated to any perspective taken in the Riacho Fundo model (Rural, Semi-urban, Urban). Besides that, the set of model fragments created to identify residues produced by different types of economic activities (thematic perspective VI) provides adequate vocabulary for each perpective. This way, entities 'Urban rf' and 'Garage' used in Urban perspective introduce vocabulary to describe how garbage produced can be transported by uncontrolled rain water runoff and affect human well being.

Grain assumptions provide different levels of details to some relevant phenomena that reappear in different contexts. Erosion is a well developed example in the Riacho Fundo model. When the Semi-urban perspective is taken, the soil aggregation process defines the value of Level of Aggregation, which in turn influences Erosion rate, and this process defines the value of Removed soil (Figure 10). A less detailed representation is adopted in Rural perspective models: Vegetation cover indirectly influences Level of Aggregation and this quantity also indirectly influences Removed soil (Figure 6). Similar options are available to represent population growth of capybara and mosquitos and in a number of other examples.

Closely related to these assumptions, approximations can produce simpler accounts for the same phenomenum that are easier to use at the cost of accuracy. For example, disappearance of springs can be addressed in simulation models when both Rural and Semi-urban perspectives are taken (simulations Rfru08, Rfru09 and Rfsu07a-b). As processes soil aggregation and erosion are not explicitly described in the Rural perspective, a model on this topic is easier to use than a similar model in the Semi-urban perspective.

Operating assumptions can be used both to give focus and to reduce the complexity of the simulations. For example, in the Semi-urban perspective models disappearance of functional springs can be caused by erosion and/or lack of undergroung water. Garp3 model ingredient Attributes was used to capture these possibilities: entity 'Spring' has an attribute 'Focus', with two possible values: 'Effects of erosion' and 'Effects of infiltration'. Depending on the attribute value introduced in the scenario, two independent causal chains may become active: (a) 'Focus: Effect of erosion': *Level of aggregation → Removed soil → Sediment → Depth → Amount of water*; (b) 'Focus: *Effect of infiltration'*: *Level of aggregation → Underground water → Amount of water*. An additional model fragment, in which 'Springs' has no attributes, allows for expressing simultaneous effects of erosion and infiltration on the springs (Salles et al., 2007; see also the simulations Rfsu 04b-c).

Similarly, different causal chains can be constructed within the Rural perspective, depending on the use of focus operating assumptions. Soil fertility can be determined in three ways: (a) by assuming that *Fertility* values correspond to *Nutrient* values; (b) by considering that vegetation cover determines the amount of organic matter, and calculating Fertility = *Organic matter* + *Nutrient*; and (c) by considering the combination of nutrients and manure, a by-product of cattle livestock (simulations Rfru03-05; see also Salles et al., 2007).

Operating assumptions are used to reduce complexity in simulations either by reducing ambiguity or preventing some behaviours to happen. Local restrictions, implemented as correspondences, were widely used in the Riacho Fundo model to reduce ambiguity and, as such, to reduce the number of states in the simulation. For example, directed correspondences between quantity values express co-occurences of values zero; correspondences between quantity spaces, co-occurrence of all possible values of two quantities. Inverse correspondences represent co-occurrence of opposite values of two quantities. Finally, correspondences between derivatives significantly reduce ambiguity in the simulation, as they determine the strongest influence when two or more proportionalities apply to the same quantity. For example, it was used to enforce *Transported garbage* to take the value of the derivative of *Uncontrolled water*, and not of *Garbage* in Urban perspective.

Local restrictions may also be implemented by means of inequalities. Examples include definitions of the level of pollution produced by economic activities: a fair level is set by assuming *Residue* < medium, no matter the amount of products; less sustainable options are *Product* ≤ *Residue* and *Residue* corresponds to *Product* (correspondence between the quantity spaces of the two quantities). As these assumptions are implemented at the level of 'Economic entity', they are applicable to the three perspectives.

Steady state assumptions reduce complexity by giving a unique behaviour to a quantity (decreasing, steady, increasing), and can be implemented both as exogenous quantities and in model fragments. Note that exogenous quantities may express more complex behaviours (Bredeweg et al., 2007) Steady state assumptions may also involve quantity magnitudes or derivatives when implemented in model fragments. In the Riacho Fundo model examples may be found in the three perspectives (e.g. *Drained water* = <zero, zero> and *Drained water* = <?, increasing> in Urban perspective).

Thematic-based perspectives were not implemented for automatic search in the current version of the Library. They are presented as suggestions for the users of the Library, so they can run specific simulations in order to answer questions about relevant themes for sustainability. Inspiration for the selection of themes come from consultations in specific literature (for example, Castells, 1996; Egger, 2006; Munier, 2006) and from the experience with the Millennium Development Goals. Of course, it was not meant to be exhaustive, but just enough to classify the knowledge encoded in the Library.

From the technical point of view, perspective-taken simulation models provide interesting views to sustainability in the basin. Assumptions are conceptually clear and pedagogical. The thematic approach fits well to everyday discussions on sustainability. However, some problems remain. Future work should focus on a higher level of integration of the input models. In fact, ideally new simulations should result from the combination of components from different input models. In order to reach this point, the use of hierarchies of model fragments, entities and of other modelling primitives should be optimized. New modelling assumptions will become necessary to take care of integrated simulations. A point that was not addressed here was the issue of shifting from one perspective to another. Identifying the requirements for such transitions will lead to better understand the nature of perspective-taking in qualitative reasoning (Liu and Farley, 1991). The thematic approach should also be reviewed and maybe enhanced with new themes. Definition of priorities in associations between simulations and perspectives was partially developed during the modelling effort of organizing this Library and proved to be very useful. For example, Global warming simulations fit better to the thematic perspective IV – environmental effects of human activities, than to the thematic perspective V – energy. Therefore, the priority should be given to the assignment of these simulations to the thematic perspective IV.

7 CONCLUDING REMARKS

The Library of model fragments comprises, in its current implementation, 112 entities, 1 attribute, 60 configurations, 201 quantities, 22 quantity spaces, 202 simulation scenarios, 414 model fragments, 24 agents and 45 modelling assumptions. It is the bigger Qualitative Reasoning of this kind to the moment.

Simulations organized in seven case study-based perspectives and 14 thematic – based perspectives seem to be enough for creating simulations about relevant aspects of sustainability in the Riacho Fundo basin. The first group of perspectives was organized with the use of assumptions and other modelling primitives, during the periods of building the models and the integration of the models into the Library. Thematic perspectives were selected on the basis of literature and explores relevant phenomena of the sustainability debate.

Simplifying assumptions facilitate vocabulary creation for each perspective, as they were used to control how entities, quantities and quantity values were introduced in the simulations. Assumptions were also effective to implement alternative views on similar phenomena, shifting from coarse to fine grained representations, according to the perspective taken. Operating assumptions provided focus and reduced complexity of simulations within each perspective.

Garp3 is an interesting tool for implementing compositional models, as it provides a rich modelling language for expressing both model components and assumptions constraining their use. Some of Garp3 modelling primitives, such as entities and configurations, attributes and agents are particularly useful for implementing perspectives. Model fragments, inequality relations, correspondences and exogenous quantities are particularly suited for implementing both simplifying and operating assumptions. This way, besides being functionally important, assumptions were also conceptually aligned to the rest of the domain knowledge represented in the library.

Although many technical questions remain unanswered, the creation of this Library is an important achievement for Qualitative Reasoning modelling. Lessons learned during the modelling effort described here will be useful for future modelling efforts. From the content point of view, the Library has the potential for significantly improving stakeholders' understanding about their everyday problems. Sustainability is a complex issue, and learning about its multitudinous aspects is an intergenerational commitment for the current generation, to properly take care of river basins still rich in natural resources and rehabilitate the damaged ones, while promoting human development for those who live in these areas.

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