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Integrated ecological assessment of rivers in Ecuador

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Abstract

The Chaguana river basin is mainly affected by human activities. Banana production and mining development impact the water quality of the principal rivers in the basin. It is affected not only the physical, chemical and biological parameters of the Chaguana river basin but the communities settled around the outlet and the shrimp farms, as well.

This research aims to develop qualitative models that allow the integration of elements in a river basin on ecosystem services of the related surface waters. Garp3 is used as modelling instrument, that in addition to the description of the interactions between the basin components, also allows to make qualitative simulations about aspects of the river basin, and how this is affecting the value of ecosystem services of the surface waters.

The building of the qualitative models depicts the structure and processes of the Chaguana system in order to gain valuable understanding of it. Hence, the development of adequate management and recommendations may be implemented in the framework of an integrated basin management. In this way, different alternatives are compared to optimize the water use in a typical river basin of Ecuador.

Acknowledgements

The execution of this thesis was feasible for the effort of several people to whom I would like to express few words.

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Introduction

Ecuador has a rich hydrographic network, thus water results in an abundant resource in the country. However, human activities are threatening the ecological status of the rivers, generating negative effects on the environment.

The Chaguana river basin is located in the El Oro Province, at the south-western part of Ecuador. The principal economic activity is intensive banana farming for exports in the lowlands which creates the main ecological impacts in the basin. As a consequence of the extent of agricultural land expansion, a decrease in water quality, habitat, and biological assemblages have been reported (*Allan, 2004*).

The government regulator (SENAGUA[1]) performs a project whereby the Technical Secretary of Water Resources, which carries out the monitoring and assessment of water quality in three main river basins since 2010. During recent years, anthropogenic burden over the water resources has observed in small-scale basins such as Chaguana basin, which are not surveyed usually.

There are integrated models, which covered different aspects of river ecosystems, however, due to the partial understanding and lack of data which constitute constraints (*Salles, 2006*) that limits their application. Qualitative models are included within the different types of integration that are needed for the effective solution of environmental problems (*Parker et al., 2002*). Since several years ago, qualitative reasoning has been introduced as an approach in which conceptual knowledge is incorporated and cause-effect relationships of situations are assessed. Lately, qualitative models have been successfully used in ecological, water management and aquatic ecosystems.

The behaviour of the Chaguana basin was designed to capture qualitative modelling based on the main human impact (e.g. agriculture). First, a general description of the system is proposed, from which the most relevant components were selected. Then, the relationships among these elements involved in the dynamics of the system were established. Garp3 is used as a diagrammatic approach in order to build and explore conceptual situation in the basin.

Consequently, the importance of this study is to represent the conceptual knowledge about the basin. Furthermore, to explore how a water body is influenced due to the main disturbances on it.

As a result, the objectives that comprise within the study are the following:

- To develop and simulate a qualitative model of the main socioeconomic activities which bring adverse effects to the system through Garp3
- To analyze results of determined scenarios representing the anthropogenic impacts at the river basin scale

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[1] New government institution is in charge of conducting an integrated management of water resources throughout the country. It was created on May 27th, 2008.

This document is organized as follows: Chapter 1 shows a synthesis of the literature review related to the work. Chapter 2 provides information about the study area and establishes the objectives of the model. Chapter 3 explains the way the knowledge was implemented into the qualitative modelling. It displays the qualitative behaviours represented by state graphs, causal views and value history views associated to integrated assessment elements chosen. Chapter 4 focuses on strengths and limitations of qualitative reasoning. Finally, Chapter 5 provides the conclusions of this work and offers recommendations for further research.

CHAPTER 1: Relevant Literature

1.1. Water quality management

According to the Global Environment Outlook (2002), the level of awareness and action has not been commensurate with the state of the global environment, and it continues to deteriorate. For instance, the environmental degradation remains and entails severe health impacts in Latin America and the Caribbean.

The ecosystem services provided by the water systems (groundwater aquifers, lake basins, river basins, large marine ecosystems and the open ocean) support the socioeconomic development and wellbeing of the population. Water resources continue to be impacted and degraded by multiple and complex human-induced and natural stresses that threaten their sustainability and, in turn, human survival and wellbeing (*UNESCO, 2010*). Also, the increasing of water consumption, waste production, food production, energy production and urbanization are crucial drivers that hamper the water availability and supply. Similarly, poor management of watersheds and water resources is observed as the major cause of land degradation.

Water quality is closely associated to the type and nature of activities and land use practices (Foley et al., 2005). Agriculture, industry, household, and recreational emissions are often driving forces that reduce the water quality. For example, it has been observed that agricultural land use degrades streams by increasing nonpoint inputs of pollutants, impacting riparian and stream channel habitat, and altering flows (*Allan, 2004*). Non-point-source agricultural pollution is considered the greatest threat to the quality of surface waters in rural areas (*Loague et al., 1998*). From the water annual consumption in Ecuador, 82.1% is used for agricultural work (*Herrera et al, 2006*) representing an important application of this resource without an adequate management of it.

A properly developed policy context is a fundamental element in the sound management of water resources (*Larsen et al., 1997*). Integrated natural resource and environmental management are increasingly becoming an objective of government policy internationally (*Jakeman and Letcher, 2003*).

In recent years, there have been reforms in legislation and organizations related to management and use of water resources in almost every country in Latin America and the Caribbean (*UNESCO, 2006*). In 2008, the National Secretariat for Water (SENAGUA) from Ecuador was created to lead and govern the processes of managing national water resources in an integrated and sustainable watershed areas, recognizing the intrinsic nature and value of water.

1.2. The need for integrated water system models

According to the Global Water Partnership (2000), Integrated Water Resource Management (IWRM) is the coordinated development and management of water, land and linked resources in order to maximize economic and social welfare without compromising the sustainability of ecosystems and the environment. The core of this process is its interconnected content among different stakeholders and sectors which are involved in the utilization of the resource.

There are several early applications in this area, for example, the New Zealand's National Rivers Water Quality Network was an important spur for the water quality management functions to support water quality research and water resources management in 1971 (*Davies-Colley et al., 2011*). Also, the application of integrated catchment management policies was introduced as state policy to overcome land and water degradation in Australia (1988) (*Zitek et al., 2009*).

In Ecuador, the use of water resources is characterized by an irrational exploitation, whereby both public and private organizations work independently and without any integrative plan (*Herrera et al., 2006*). The management of water resources has not been of main concern during the last governments; as a result there has been no specific path towards an IWRM.

The integration in natural resource assessment has several dimensions and it extends to models of the different system components and the incorporation of multiple databases. The development and use of models are major activities of integrated assessment, and this is because people think and communicate in terms of models as simplifications of reality (*Jakeman and Letcher, 2003*). Therefore, the qualitative models play an important role to improve an integrated assessment.

The implementation of IWRM requires from water managers and planners a good understanding of the system dynamics, which most of the time is hold by specialists from different scientific fields. Since the management and science interchange is still limited in many countries, proper mechanisms are needed to guarantee a continuous information transfer to decision makers and water regulators (*Nolivos, 2010*). One important step towards an IWRM is to give more tools, e.g. modeling, to the basin's stakeholders in order to achieve a better supervision approach for the resources.

1.3. Qualitative reasoning modelling

Falkenhainer and Forbus (1984) introduced the Qualitative Process Theory as a representational framework in order to understand complex physical reasoning. Subsequently, Falkenhainer and Forbus (1991) brought out the compositional modeling strategy as an important step towards understanding how to build and use different domain models.

Conceptual models are defined as models that improve our understanding of systems and their behavior (*Bredeweg and Salles, 2009*). These types of models are understandable, manageable, and capable of being fully explored, can be help in attaining an understanding of ecological systems and process (*Grimm, 1994*). It is important to know and comprehend the nature of the ecosystems in order to acquire reasonable explanations of the interactions of each component within a community of living organisms. Qualitative Reasoning technology is well suited to model and simulate such conceptual knowledge (*Bredeweg, 2009*)

Qualitative Reasoning is an approach from Artificial Intelligence that provides means to express conceptual knowledge such as the physical system structure, causality, the start and end of processes, the assumptions and conditions under which facts are true, qualitative distinct behaviors, etc. (*Bredeweg et al., 2009*). In this way, qualitative modelling can help learners to express and externalize their thinking (*Schwarz and White, 2005*).

The major issue of qualitative reasoning is to provide general formalizations allowing them to abstract the main relevant features of the complex real world. These allow one to represent and integrate expert knowledge and implement it as models with good self-explanatory facilities (*Guerrin and Dumas, 2001*). In this way, behaviour processes of an ecosystem are represented qualitatively.

Qualitative Reasoning models can be used as tools for education and decision-making, particularly in domains such as ecology for which numerical data is often unavailable or hard to come by (*Cioaca et al., 2009*). Conceptual models based on qualitative reasoning are valuable tools both for pre-mathematical modelling, and as standalone artifacts developed for understanding, predicting and explaining the system's behavior (*Bredeweg and Salles, 2009*).

1.4. Components of a qualitative reasoning engine

An important goal of a typical qualitative reasoning engine is to automate the knowledge and by doing so to support humans in analyzing how the behavior of a system evolves as time passes. To perform such a task, a qualitative reasoning engine takes a scenario as input and produces as output a state graph capturing the qualitatively distinct states a system may manifest (Figure 1-1) (*Bredeweg and Salles, 2009; Bredeweg et al., 2005*).

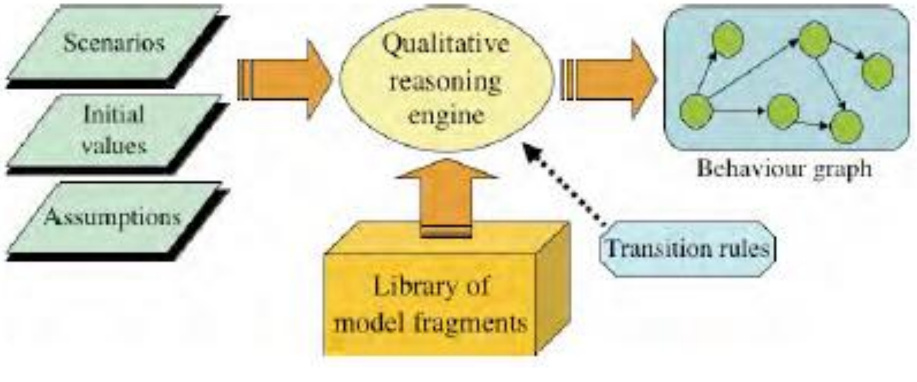


Figure 1-1 Basic architecture of a qualitative reasoning engine (Bredeweg et al., 2005)

A *scenario* is an initial description of the system subject of the reasoning (*Bredeweg and Salles, 2009*). It usually includes a structural description of the physical appearance of a system, accompanied by statements about initial values and assumptions (*Bredeweg et al., 2005*).

A *state graph* (or behavior graph) consists of a set of states and transitions between those states. A *state* refers to a qualitatively unique behavior that the system subject of reasoning may manifest in reality (a 'possible state of behaviour'). A *state transition* specifies how a particular state of behaviour may change into another. A sequence of states, connected by state transitions, is called *behaviour path* (a 'possible behaviour') of the system. To construct a state graph, the reasoning engine uses a library of predefined partial models. These model fragments represent chunks of domain knowledge and, depending on the scenario details; subsets of these fragments are assembled by the engine (*Bredeweg and Salles, 2009; Bredeweg et al., 2005*).

As it was pointed by Falkenhainer and Forbus (1991), compositional modeling uses explicit modeling assumptions to decompose domain knowledge into semi-independent model fragments, each describing various aspects of objects and physical processes. In this manner, the combination of the model fragments is like pieces of knowledge about certain domains associated with values and initial assumptions to examine the behaviour of a set of system.

1.5. Knowledge representation

Qualitative models developed in Garp3 encompass different key ingredients: *Entities* which represent the components of the system. They form an important backbone to any model that is created. Entities are organized in a subtype hierarchy (*Bredeweg and Salles*, *2009*). Entities are related to each other by means of *Configurations*. The configurations define the structural relationships of the basic system assembly and mainly describe the direction and type of influences (*Zitek et al., 2009*). Attached to the structural model are *Quantities*, variables that represent the dynamic properties of each system entity (*Nakova et al., 2009*).

A quantity is represented by two aspects <*magnitude, derivative*>. The former expresses the 'amount of stuff' present (e.g. {small, medium, large}) and the latter the direction of change (e.g. {minus, zero, plus}). The value from derivative of the quantity means whether it is decreasing, stable and increasing, respectively. Possible values for quantities are represented as points and intervals presented as an ordered set called *quantity space* (*Araujo et al., 2008*).

A process can be defined as a mechanism that cause changes along time in the system (*Salles, 2009*). In the Qualitative Process Theory (*Forbus, 1984*), it is assumed that changes in the system are initiated by processes that become active and then may propagate to other quantities in the system.

Consequently, qualitative reasoning provides primitives in order to exemplify the causality. *Influence*s represent direct causal relationships between two quantities, and are presented in the form of positive and negative direct influences (Influences: I+, I-). *Proportionalities* propagate the changes to other quantities created by the direct influences, and are positive or negative (Proportionalities: P+, P-) (*Cioaca et al., 2009*).

Processes are modelled by direct influences representing a rate that is used to calculate the value of the derivative with respect to time of a state variable. Direct influences are qualitative representations of ordinary differential equations with time as the independent quantity (*Araujo et al., 2008*). For instance, it can be defined as follows:

$$\text{I+ (State variable, Rate)} \leftrightarrow d\,\text{State variable} / dt = \ldots + \text{Rate} \ldots$$

On the other hand, qualitative proportionalities also have mathematical meaning. For example, the relation P+ (Auxiliary variable, State variable) indicates that the auxiliary variable is linked to state variable by means of a monotonic function so when the state variable is changing (i.e. increasing or decreasing) then auxiliary variable will change in the same direction (*Salles, 2009*). As it was mentioned before, besides their mathematical meaning, both influences and proportionalities represent causality. Therefore, a causal chain is generated:

$$\text{Rate} \rightarrow \text{State variable} \rightarrow \text{Auxiliary variable}$$

Additional dependencies embrace several types of correspondences designating specific value in the quantity space (V-correspondence) or between the whole quantity spaces (Q-correspondence). Inequalities $\{<, \leq, =, \geq, >\}$ may establish relations either between a quantity and a specific value (of magnitude or derivative), or between two quantities (*Nakova et al, 2009*).

1.6. Model evaluation

Evaluation of the simulation models entails verification and validation which are considered crucial parts in the development of the model in order to assess whether the simulations and the model as well, are correct and reliable. Model validation and verification are related to a simplified version of the modelling process, which it is represented in Figure 1-2. Rykiel (1996) and Sargent (2008) approaches of verification and validation are contemplated in this section.

Ecological models are built for scientific research purposes, but increasingly for water resources management and environmental sustainability purposes. From the ecological research perspective, special implication is pointed out to the model verification and evaluation of conceptual validity (*Bredeweg et al, 2007a*). Model verification is defined as ensuring that the computer program of the computerized model and its implementation are correct. Model validation is defined as substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model (*Sargent, 2008*). From Figure 1-2, operational validation, conceptual validation, and data validity denote the validation process of the model.

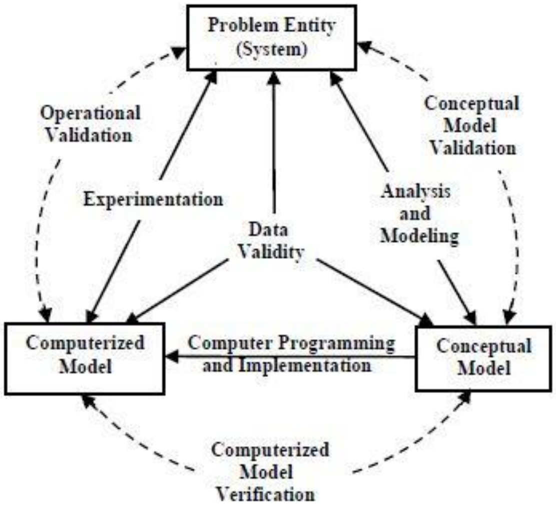


Figure 1-2 Representation of the simplified description of the modeling process

Conceptual model validation is meant that the theories and assumptions underlying the conceptual model are consistent with those in the system theories and that the model representation (i.e. its structure, logic, mathematical, and causal relationships) of the system is reasonable for the model´s intended use (*Rykiel, 1996*). In this way, conceptual validity depends on providing a scientifically acceptable explanation of the cause-effect relationships included in the model.

1.7. Qualitative reasoning as a tool in water resources management

In order to be able to manage natural system's responses to achieve specific outcomes, humans need first to understand how the system performs under different conditions (*Nolivos, 2010*). Therefore, models which predict and assess the impact of different activities on natural resources should be assigned to assist a better understanding of ecosystems properties and a better ecosystem management by assessing the consequences of critical situations, reasoning and planning actions (*Guerrin and Dumas, 2001*).

Qualitative reasoning has been successfully used for ecological modelling, particularly when numerical data are not available (*Araujo et al., 2008*). Additional research has been developed regarding to sustainability within the Sixth Framework Programme for Research and Development (2002-2006) (i.e. project NaturNet-Redime). Also, Salles (2009) introduced qualitative representations of environmental indicators for monitoring the Millennium Development Goals related to environmental sustainability in Brazil. Furthermore, Cioaca et al. (2009), Nakova et al. (2009), and Zitek et al. (2009) conducted research on qualitative models focusing on sustainability on water basin level.

CHAPTER 2: Materials and methods

In this chapter, Section 2.1 gives details about the work entailed in constructing models. Section 2.2 describes the study area highlighting important information about the basin, and formulates the goals of the models.

2.1. Framework for building qualitative models and simulations

Building a qualitative reasoning model is a complex task. It requires the development of a library of model fragments and accompanying scenarios such that simulation of those scenarios produces output that satisfies the modelling goals (*Bredeweg et al., 2007a*). Therefore, a protocol introduced by Bredeweg *et al.* (2005 and 2007a) is implemented in order to construct a structured approach to execute the modelling of the present study. This structured framework composes six steps which are listed below:

A. Orientation and initial specification: the modeller creates a concept map and defines the model goals.
B. System selection and structural model: a subset of the concept map details is refined and adapted into the structure map.
C. Global behaviour: representations of processes and actions, causal map, scenarios, and expected behaviours map are captured in this step.
D. Detailed system structure and behaviour: detailed specification of the behaviour to be captured.
E. Implementation: creation of the model ingredients in the model building software, simulation, and debugging to improve and optimize the model and obtain the required results.
F. Model documentation: documentation of the model and underlying argumentation (*Bredeweg et al., 2005 and 2007a*).

The model presented in this study was accomplished in Garp3. This software is a user-friendly workbench that allows modellers to build, simulate, and inspect qualitative models (http://www.Garp3.org). It uses a diagrammatic approach for representing model content, and graphical buttons to communicate the available user options and manipulations (*Bredeweg et al., 2009*).

The Chaguana river basin model involves 14 entities, 8 configurations types, 1 agent, 30 quantities, 43 model fragments, and 5 scenarios. The latter components of the model are considered as ingredients and depict the implementation details of the model.

Accordingly, simulations of scenarios comprise the model output and constitute the link among the component causal relationships and the relevant aspects influencing the river basin. Detailed information about the Chaguana basin model is described further in this document.

2.2. Context and model objectives

The main goal of the orientation and initial specification step is to developing a broad understanding of the phenomena that will be modelled (*Bredeweg et al., 2007a*). A first proceeding, the ideas of a specific situation in this case the Chaguana basin, is conceptualized to establish a model. This step consists of different aspects which are important references during the model building process (*Bredeweg et al., 2007a*). The goals and concept map of the models are described more in details in the following subsections.

2.2.1. Study area

The predominant characteristics of the Chaguana river basin are defined which include the major disturbances threatening this area. The outline presented below is illustrated to provide the essential background information of the Chaguana river basin. It supports to study and diagnose the target system.

Chaguana basin was selected for the present study due to available research by Matamoros (2004), Dominguez (2007) and Nolivos (2010) in this region. Nevertheless, hydrological observations, river water quality measurements and soil and ecological data are still scarce in general.

Each research covered different aspects, but all were focused on the Chaguana basin. In reality however, monitoring campaigns, proper management and restoration actions are not frequently carried out in Ecuador and as a result, it is difficult to implement adequate management strategies. This river basin can be seen as a reference of an area where economic activities (e.g. agriculture, aquaculture and mining) are being developed and are affecting human health and environment.

The Chaguana basin: It is located in the southern coastal part of Ecuador, within the El Oro Province (Figure 2-1). This river basin is approximately 32,000 hectares (ha) (*Matamoros, 2004*). It could be considered as a hydrological system between a rural catchment and a river basin (*Maidment, 1996*). The Chaguana basin drains a relatively complex mountainous area of difficult access through perennial streams and rivers. Head waters in this area are located up to 2900 m.a.s.l. (meters above the sea level) (*Dominguez, 2007*).

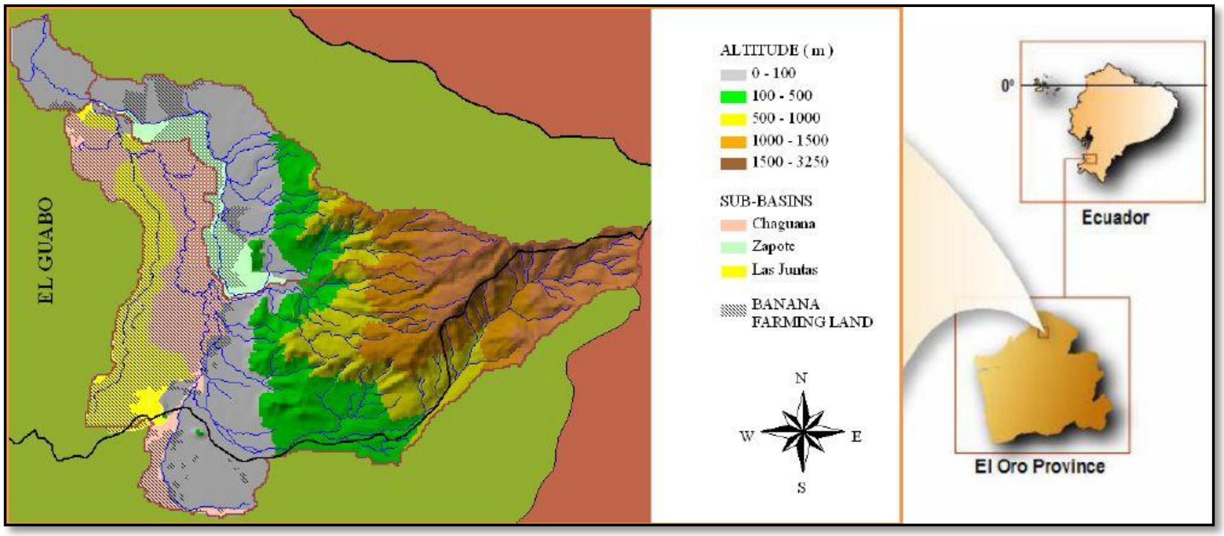


Figure 2-1 The Chaguana river basin (Nolivos, 2010)

The Chaguana system has two main rivers: Zapote and Chaguana. Zapote River joins the Chaguana River approx. 5 km before the basin outlet. The Chaguana system does not discharge directly into the Pacific Ocean, but to a bigger watershed called the Pagua River Basin. However, tidal influences can be noticed up to 6 km upstream of the Chaguana basin's outlet (*Matamoros, 2004*).

Its topography records a difference in elevation of around 3000 m in an area of 320 km^2 (i.e. the maximum elevation is 3267 m.a.s.l. and the minimum is 1 m.a.s.l. near the basin outlet) (*Nolivos, 2010*). The banana sector in the basin is mainly located between 4 and 60 meter elevation levels (*Matamoros, 2004*).

The water regime in the Chaguana river basin is mainly influenced by the annual climate variability, with two marked periods: the rainy (i.e. December to May) and dry (i.e. June to November) seasons (*Nolivos, 2010*). Within the basin, there are three existing flow gauging stations from the former National Institute of Water Resources. However, their records are not so reliable due to missing data, non-continuous period of measurements and some other drawbacks. Based on the registered data, the median values of river flow reported per month in the basin are between 0.2 and 4.4 m^3/s, with highest flows being observed in April and November (*Matamoros, 2004*).

Major human settlements in the basin are located in the lowlands, at the western part. They mainly consist of rural populations from two municipal governments: El Guabo and Pasaje; giving a total population of around 7600 inhabitants (*Dominguez, 2007*). The basins territory is mainly under the jurisdiction of the El Guabo Municipality, which encloses around eighty percent of the area together with most of its rural population (*Matamoros, 2004*).

Agricultural sector in Ecuador: Banana is the first agricultural commodity in Ecuador. The Ecuadorian Ministry of Agriculture, Livestock, Aquaculture and Fisheries registered a total sown area of 229,602 ha in the country in 2009. El Oro is the province with the second largest area of total cultivated banana in Ecuador with approximately 56,887 ha (*INEC, 2009*). It represents 25% of the cultivated surface area in the country. From the water annual consumption in Ecuador, 82.1% is used for agricultural irrigation (*Herrera et al., 2006*).

Land use in the basin: The Chaguana basin is predominantly an agricultural basin, with agricultural land use activities covering 55% of the watershed surface (*Dominguez, 2007*). Banana production is the most important agricultural activity in the basin comprising 26% of the agricultural surface area (Figure 2-2) (Matamoros, 2004).

The classification, according to the size of the banana farms, shows that the small and medium farms are mainly located at the upstream of the river basin while the big farms are downstream. During sampling campaigns by Matamoros (2004) the downstream section of the banana sector showed pesticide concentration values higher than the ones obtained in the upstream section of banana activity.

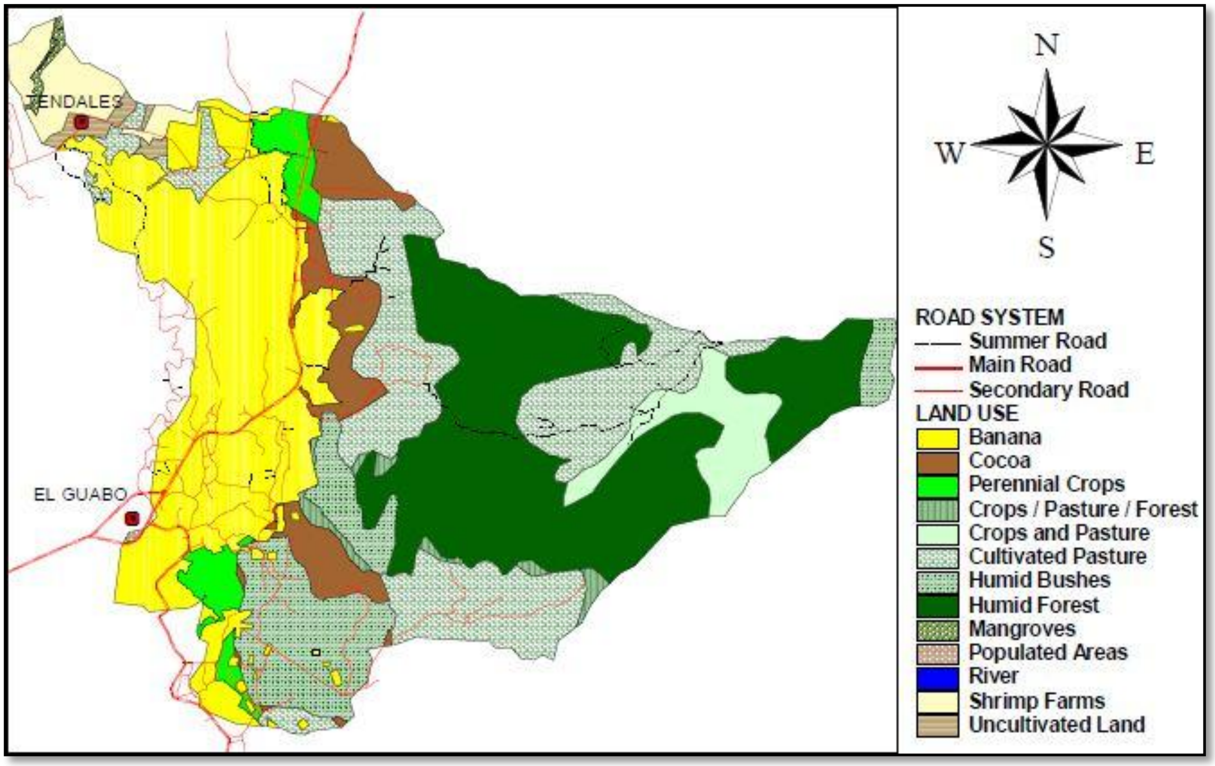


Figure 2-2 Land use in the Chaguana river basin in 2004

Near natural areas (humid forests and brushes, mangroves and uncultivated lands) represent 37% of the total surface of the basin (*Dominguez, 2007*).

The banana crops inside the Chaguana basin are intensive mono-cropping systems of small (up to 30 ha), medium (30-100 ha) and big size (larger than100 ha), producing mainly for export (Table 2-1). Although only 6% of the farms in the basin have an area larger than 100 ha, they cover almost 50% of the productive land and employ an important portion of the basin´s population (*Nolivos, 2010*). It is relevant to highlight the incomes that generate the production of this crop for the country but without leaving aside all environmental effects which should also be taken into account. An ecological responsibility should be promoted basing on state policies to include new sustainable changes.

Table 2-1 Farm distribution per size in the Chaguana basin (Matamoros, 2004)

Farm size	Percentage	Average size (ha)
Less than 30 ha	80.2	10.6
30 ha – 100 ha	13.8	52.2
More than 100 ha	6.0	186.5

The production system of banana in the big farms involves irrigation, drainage, fertilization and aerial fumigation of the plants with pesticides to control the black sigatoka disease. Furthermore, practices such as construction of artificial embankments (i.e. for irrigation pumping), removal of the river bed sediments (i.e. for deeper canals), clearance of riparian vegetation and artificial river embankment for flood alleviation are performed leading to structural and morphological disturbances (*Dominguez, 2007*). Therefore, streams in highly agricultural landscapes tend to have poor habitat quality, which is reflected in declines in habitat indexes and bank stability (*Allan, 2004*).

Water quality: Information to determine the quality of the river water in the basin is limited. Data about the water quality indices has been collected during different campaigns considering the climate periods of a year (i.e. dry and rainy seasons). Physico-chemical parameters like dissolved oxygen, oxygen saturation, pH, water temperature, salinity and electrical conductivity have been determined, next to river characteristics such as altitude, stream current, width and depth. In addition, solids content (i.e. suspended solids and dissolved solids); biochemical oxygen demand and pesticide concentration have been measured.

Matamoros concluded that the basin was not heavily polluted during his research and complies with the majority of quality standards. However, the two major residential areas located at the western part of the Chaguana basin (i.e. Tendales and El Guabo) could potentially contribute to the organic pollution of the river since wastewater treatment plants in the area are not present.

Similarly, Dominguez (2007) revealed that the basin at the moment of sampling was not heavily polluted by organic compounds, and therefore, habitat degradation related to the intensive agricultural activities is probably the main stressor of the riverine macroinvertebrate fauna.

During 2002, maximum values of pesticides (i.e. around 6 parts per billion -ppb-) were detected in the basin. That is significantly below the reported toxicity values for aquatic organism. Therefore, the pesticide impact on the Chaguana basin on the aquatic biota is relatively low. However, detected pesticide values are exceeding the European maximum residue levels in water for human consumption (0.5 ppb for the total amount of pesticides, and 0.1 ppb for one pesticide). Therefore, human health must be the main concern related to the pesticide usage in the Chaguana Basin. As the people living in the Chaguana basin do not have potable water systems, they may be taking water directly from the river. Consequently, there is a potential risk to human health (*Matamoros, 2004*).

Sanitation: In Ecuador, most of the rural population settled on agricultural areas lack potable water distributed by drinking water services, surface waters are generally used for cooking, bathing, drinking and washing cloths (*Dominguez, 2007*). Population inside the Chaguana river basin is mainly rural and sparse, with few small villages and towns settled near the basin outlet (*Nolivos, 2010*). There are only two important residential areas located at the most western parts of the basin: Tendales and El Guabo (see Figure 2-2).

Access to potable water is limited to urban populations. From a total of 1626 houses within the basin, only 32% possess connection to a piped water supply, 37% obtain water from deep wells and 26% from superficial waters bodies (e.g. canals within the farms, streams, and rivers in the basin). Access to improved sanitation facilities (e.g. sewage system) is also limited. Only 7% of the houses within the basin are connected to a sewage drain system, while 43% is discharging over land, 28% to dry wells and 22% to septic tanks (*Dominguez, 2007*).

Most human settlements do not possess sanitation; with some of them having limited access to pipeline water. By 2001, sixteen percent of the houses in the Chaguana basin, located near the Chaguana river basin outlet, were still consuming water from contaminated rivers and canals (*Chang, 2003*).

Aquaculture: According the Ecuadorian Centre of Integrated Survey and Remote Sensing (1999), shrimp farms cover an area of 944 ha or 3% of the total surface area in the basin. The shrimp area is located mainly near the outlet of the basin (see Figure 2-2).

On the other hand, the impact of shrimp farming of most concern is the destruction of mangroves and salt marshes for pond construction (*Paez-Osuna, 2001*). The destruction of these highly valuable ecosystems can have a big impact on the region’s water resources and environment.

Mining: According to environmental surveys carried out in several gold mining districts in Ecuador, the main contaminants released in the environment by mining are cyanide, heavy metals and mercury, which are discharged directly or indirectly into the rivers due to inadequate disposal systems (*Sandoval, 2001*). Gold mining is an activity mainly developed in the El Oro province where the Chaguana river basin is located. It is becoming an environmental issue for this area as it is not management properly. Artisanal small-scale gold mining has negative impacts on the riverine ecosystem as well as on the health of the human population in the El Oro Province (*Dominguez, 2007*).

2.2.2. Model goals

A model is always created to serve a purpose, and model goals should particularly address which characteristics of the target system will be captured in the model and how they will be observable in simulation results (*Bredeweg et al., 2007a*). The Chaguana basin model will focus on the most important environmental impacts, with contamination from agriculture and mining being identified as the principal ones. In order to fulfill its purpose, the model has the following goals:

- To describe the behaviour effects of anthropogenic activities (agriculture and mining) in the watershed
- To express relationships between the integrated assessment components in the watershed

CHAPTER 3: Results

This chapter describes how the conceptual knowledge was gathered through the model ingredients scheme to its application in the Garp3 simulator. The latter was achieved based on the framework mentioned in Section 2.1. Also it was focused on the implementation of the model in the qualitative reasoning software.

3.1. Chaguana river basin concept map

A concept map was developed in order to capture the structure of the Chaguana system. A concept map is a graphical representation that consists of two components: nodes and arcs. Nodes reflect important concepts, while arcs show the relationships between those concepts (*Liem et al., 2010*).

Concept maps have been demonstrated to be an effective means of representing and communicating knowledge (*Cañas et al., 2004*). DynaLearn is an Interactive Learning Environment (ILE) that offers a constructive approach for developing a conceptual understanding of how systems work (*Bredeweg et al., 2010*). The DynaLearn ILE provides six learning spaces where the first one is meant to allow the definition of the key concepts and relationships in a domain (*Liem et al., 2010*). Through learning space 1, the current situation is represented showing its components and how they determine the state of this basin. As it was established above, agriculture is the main activity in the lowlands of the basin. Most of the banana farms are more than 100 ha big and conduct intensive agricultural practices.

At the same time, mining development is increasing in the highlands of the area during last years. The Chaguana river basin is affected by these two socioeconomic activities. Furthermore, aquaculture farms and human settlements located around the mouth of the Chaguana into another basin threaten the health and welfare of the El Oro communities. Lastly, Figure 3-1 points out the major sources of stress due to human activities in the Chaguana basin.

3.1.1. Global structure and behaviour

In this section, the outputs created during the ‘system selection and structural model’ and the ‘global behaviour’ steps are presented. The goal in this second part is to identify the system structure (i.e. particularly the entities involved and how they are related), distinguishing the system from its environment, and clarifying the assumptions made while specifying the structure of the system (*Bredeweg et al., 2007a*) which constitute its two subparts.

For the Chaguana river basin, the structural model is focused on the water use, habitat characteristics and human actions developed in the environment of the basin.

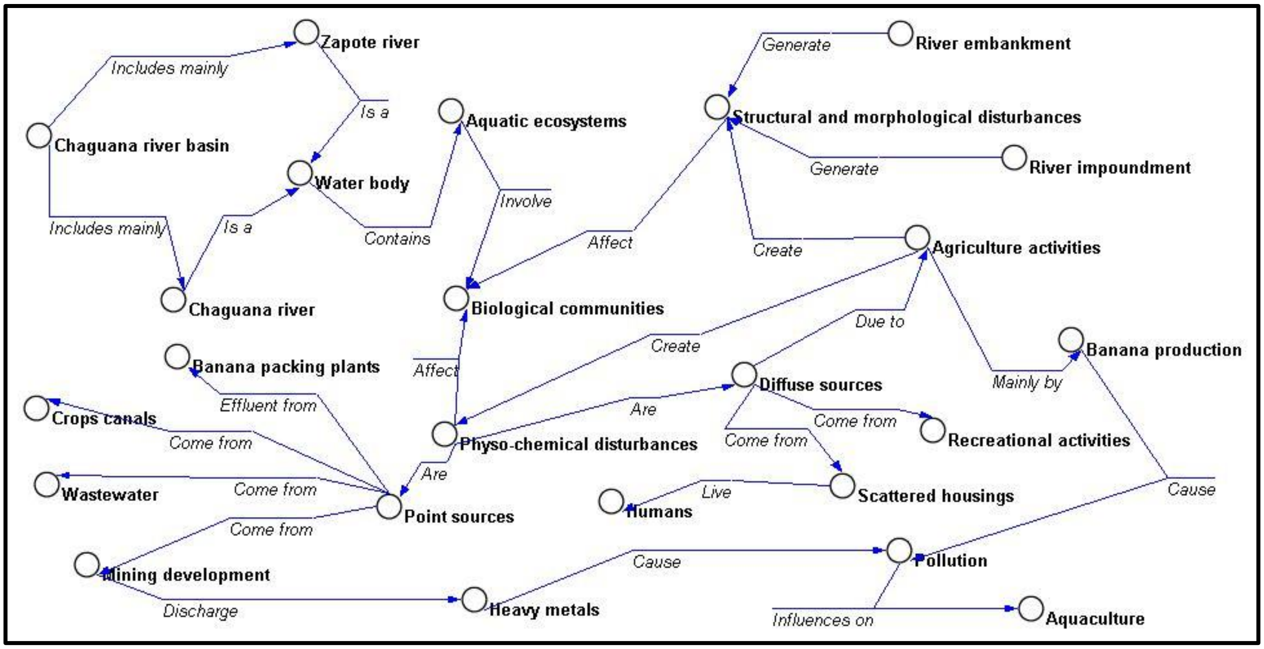


Figure 3-1 Concept map of the Chaguana basin

3.1.2. Global structure

Chaguana basin system structure: in Figure 3-2, the system structure refers to the physical world as perceived by humans. It points out those parts of the system that in principle do not change due to the behaviour of the system (*Bredeweg et al., 2007a*) and it is formed by the entities.

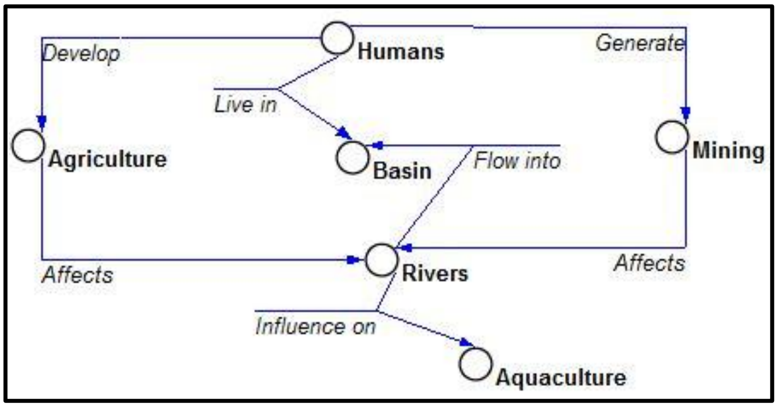


Figure 3-2 Structural model map for the Chaguana basin system

System entities: from the concept map and model goals, the entities for the Chaguana river basin were determined; the entity summary is depicted in Table 3-1.

System environment and external influences: during the building of Chaguana basin model, some aspects were not taken into account because they are outside of the system boundary and depend on other aspects. The main economic activities developed within the basin are considered the system which may have an effect on the water resource. However, the actions by government for proper river basin management are not part of the system as such.

Assumptions concerning structure: the loss of nutrients in agricultural runoff only consists of the surface runoff without taking into account the subsurface flow. Pesticides spraying are aerial and by land. Small-scale mining is only considered in the basin because it is assumed that median or greater mining have proper management of disposal. Moreover, the illegal mining (i.e. which has no concession by the government) and small-scale mining (i.e. most of them artisanal) are the major pollutants of rivers.

Table 3-1 Description of the relevant entities

Entity	Description
Basin	The ecological unit considered for this study (i.e. Chaguana river basin).
River	The aquatic ecosystem where biotic components live.
Agriculture	The main land use within the basin.
Mining	Human activity which has gradually developed in the basin.
Human settlements	This entity is related to the inhabitants that are located inside the basin.
Aquaculture	Another land use located at the mouth of the Chaguana river basin.
Biota	Group of the organism which it is represented by macroinvertebrates and riverine vegetation.

3.1.3. Global behaviour

The goal of the global behaviour is to establish gradually specific model details through the notion of processes, causal model, scenarios and behaviour graphs, and assumptions (*Bredeweg et al., 2007a*). The overall idea is to represent the different aspects of the system nature in a specific direction and reuse the aspects when it is suitable.

Processes: in order to state a specific behaviour, identification and description of the processes that regulate entities is a crucial aspect. Quantities grasp qualitative information which is captured by its qualitative values. Quantities and quantities spaces are related with the behaviour of the system, showing variable features of entities. The main processes are described according to the entity involved and are presented in Table 3-2.

Causal model: when specifying the causal model, the main objective is to create an overview of how the effects of processes propagate to other features (quantities) of the system and how processes interact (*Bredeweg et al., 2007a*). Causal models are representations generated by Garp3 during the simulation of a qualitative model. The rectangles symbolize the entities and agents. Also, direct (I+/I-) and indirect (P+/P-) influences constitute the causal dependencies.

Table 3-2 Processes involved in the Chaguana basin Part 1

Name	Entities	Quantities (rate/state variable)	Effect	Start/Stop conditions
Sewage emission	⇒ Human settlements ⇒ River	- Household discharge (r) - Amount of sewage (sv)	It is the process of contamination by the open discharge for the disposal of domestic dirt. It can influence the pollution concentration and the aquatic population of the river.	This type of emission occurs because the lack of wastewater treatment plans. As a result, waste is deposited in the river as starting conditions. It could increase the amount of sewage with a high a population growth. Stop conditions are related with action plans controlling the situation.
Agriculture intensification	⇒ Banana farms	- Agricultural intensification (r) - Agricultural runoff, Irrigation activities (sv)	Banana farms as the main crop in the basin. This activity could create negative effects on the processes of the river.	Labors related with irrigation, fertilizer and pesticide applications. In normal conditions, this process is always active and is developed in the basin’s lowlands. However, it is stronger because the intensive mono-cropping farms cover almost 50% of the productive land.
Mining	⇒ Small scale gold mining	- Mining disposal (r) - Heavy metals (sv)	The concentration of heavy metals could rise and disturb the biological communities which inhabit the river. Humans may also be affected.	Artisanal mining produces mining waste due to the lack of correct management. Recently, small scale gold mining has increased in the area.

Table 3-2 Processes involved in the Chaguana basin Part 2

Name	Entities	Quantities (rate/state variable)	Effect	Start/Stop conditions
Water pollution	⇒ River ⇒ Macroinvertebrates ⇒ Shrimp farms ⇒ Human settlements	- Pollution load; Inflow water pollution (r) - Stressor factor, Contaminated flow, Tendency to disease (sv)	It is the process to contaminate water bodies. In the case of the Chaguana river basin, the pollutants consist of heavy metals, pesticides and nutrients. Also, it is divided into pollution of the river as consequences of human activities, and then this polluted water is used as a resource in aquaculture.	Starting conditions: When increasing of intensive agriculture and mining disposal are active. Stop conditions: Low concentration of water in the pollutants.
Vegetation growth	⇒ Riverine vegetation ⇒ River	- Vegetation growth (r) - Vegetation presence (sv)	This process contributes to the vegetation presence adjacent or in the water body which have an effect for the macroinvertebrates birth.	Regeneration of the riverine vegetation maintains the vegetation; conversely, happens when deterioration increases.
Birth Mortality	⇒ Macroinvertebrates	- Birth, Mortality (r) - Population density (sv)	Both processes influence on the population density of macroinvertebrates.	Better conditions of the habitat where macroinvertebrates live have an effect on the birth. On the other hand, degradation of their habitat increases the mortality of them.

Full causal models are shown in the chapter of results. Figure 3-3 illustrates an example only for demonstration purpose.

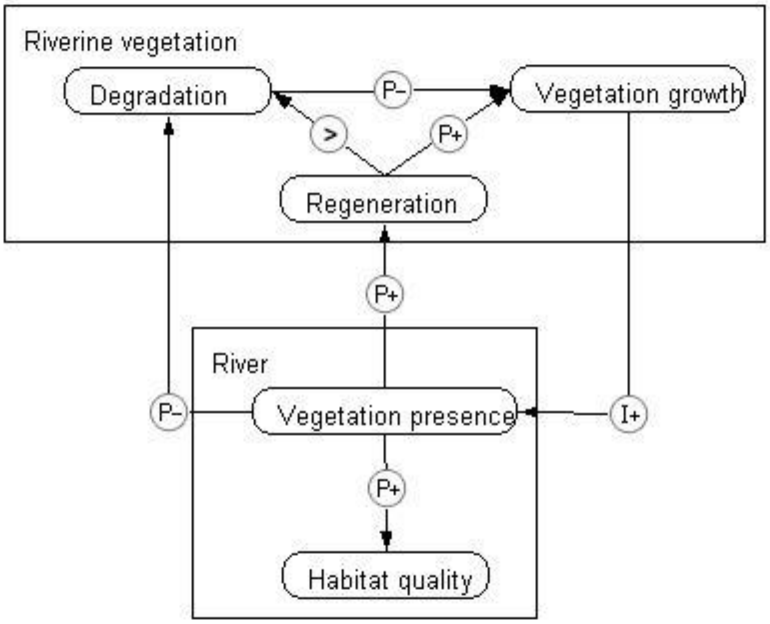


Figure 3-3 Overview of quantities and their causal dependencies

The representational means used in the previous figure reads as follows:

- If the process of growth of riverine vegetation is active and the growth rate is positive, it causes the presence of vegetation in the river to increase; then there is an I+ relation between these quantities.
- If vegetation presence increases, then habitat quality will increase (P+) because, for instance, macrophytes grow in or near water which are either emergent or floating. These plants support an environment for macroinvertebrates providing ecosystem services.
- If vegetation presence increases, then regeneration of riverine vegetation also increases (P+). Notice that there is a feedback loop here which it is reflected in the vegetation growth.

3.2. Model development and implementation

A detailed description of all model ingredients that constitute the implemented model is presented in the following subsections.

3.2.1. Entity hierarchy, configurations, and agents

The entity subtype hierarchy for the Chaguana basin is based on the structure shown in Section 2.3.1. Entities are depicted into a subtype hierarchy in Figure 3-4. It refers to the decomposition of the entities. For instance, agriculture consists of the subpart 'Banana farms'.

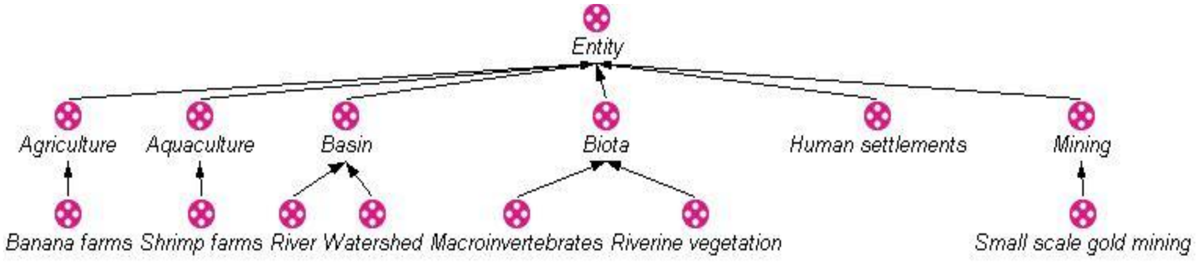


Figure 3-4 Entity hierarchy for the Chaguana basin model

In Table 3-3, the entities are related to each other by means of configurations. There are eight types of configurations used in the models.

Table 3-3 Configurations employed to represent the system structure

Entity source	Configuration	Entity target
Banana farms	*Affect*	River
Banana farms	*Located in*	Watershed
Human settlements	*Live around*	River
Macroinvertebrates	*Live in*	River
River	*Influence on*	Aquaculture
River basin management	*Implemented on*	Watershed
Riverine vegetation	*Bordering along*	River
Shrimp farms	*Located in*	Watershed
Shrimp farms	*Depend on*	River
Small scale gold mining	*Affect*	River
Watershed	*Influence on*	River

Agents are used to model entities outside the modelled system and influence the rest of the system. Agents are referred as exogenous or external factors (*Nakova et al, 2009*). This study aimed to contribute to the river basin management especially in the agriculture zone due to its possible impact. Toquilla straw plant (*Cardulovica palmata*) has shown proper characteristics for covering water bodies from pesticides applications. The use of toquilla straw plant in the buffer zone is an option within the river basin management. It is represented as an agent and is active in the Chaguana basin model for scenario #5. It is exemplified in the causal model with a dashed line.

3.2.2. Quantities and quantity spaces

The quantities and their sets of possible qualitative values are presented in the following Table 3-4. The quantity spaces are classified as follows: Zp= {zero, plus}; Mzp= {min, zero, plus}; Zlh= {zero, low, high}; Zlmh= {zero, low, medium, high}; Pfge= {poor, fair, good, excellent}; Zpc= {zero, probable, critical}. Note that plus means active or presence.

Table 3-4 Quantities in the Chaguana basin model Part 1

Entities or agent	Quantities	Quantity Spaces	Remarks
River	Pollution load rate	Zlmh	Presence of contamination which could create an impact in other stakeholders
	Eutrophication	Zp	Depicts the enrichment of water bodies by nutrients
	Habitat quality	Pfge	Represents the physico-chemical processes that occur in the surface water body
	Nutrients	Zlh	Denote the components that are introduced for agriculture or sewage waste
	Heavy metals	Zlh	Denote the heavy metals pollution caused by mining production
	Sewage waste	Zlh	Describes the amount of waste which comes from inhabitants within the basin
	Pesticides	Zlh	Represent the chemical products (e.g. fungicides, herbicides) used in the banana farms
	Vegetation presence	Zlmh	Refers to the ecosystems that exist near side or in river
Human settlements	Household discharge rate	Zp	Characterizes the emissions from population which lives within the basin
	Tendency to diseases	Zp	Denotes the incidence that diseases occur among the human communities which live around the river

Table 3-4 Quantities in the Chaguana basin model Part 2

Entities or agent	Quantities	Quantity Spaces	Remarks
Banana farms	Agriculture runoff	Zp	Illustrate the inputs used in banana farms such as fertilizers and pesticides which are applied according the farm size
	Agricultural intensification rate	Mzp	Depicts the rate of the cultivation of land with inputs of pesticides and fertilizers in order to achieve maximum output
	Irrigation activities	Zp	Denote the structural and morphological impacts by water extraction (e.g. construction of artificial embankments)
Small scale gold mining	Mining disposal rate	Zp	Depicts the waste generated by small-scale gold mining within the basin (e.g. mercury)
Shrimp farms	Contaminated flow	Zlmh	Illustrates the polluted water supply in order to develop aquaculture based on the water quality
	Inflow water pollution rate	Zp	Describes the rate of water polluted as source to the production in shrimp farms
	Inflow water quality conservation	Zlmh	Denotes actions carried out for preservation of inflow water
	Inflow water quality deterioration	Zlmh	Related to factors that decrease the inflow water quality

Table 3-4 Quantities in the Chaguana basin model Part 3

Entities or agent	Quantities	Quantity Spaces	Remarks
Macroinvertebrates	Birth rate	Zp	Refers to population process which change number of macroinvertebrates
	Mortality rate	Zp	Refers to population process which change number of macroinvertebrates
	Population density	Zlmh	Represents groups of macroinvertebrates used to assess water quality state
	Stressor factor	Zp	Depicts the effects on the characteristics of a water body system
Riverine vegetation	Degradation	Zlmh	Related to the destroyed vegetation by natural or human way
	Regeneration	Zlmh	Describes the vegetation restored in a natural way or by human influence
	Vegetation growth rate	Mzp	Represents the development of vegetation and is influence by regeneration or degradation
Watershed	Nutrients runoff	Zlh	Denotes the surface runoff which supplies the water input to aquatic ecosystems accompanied with fertilizers
	Pesticides runoff	Zlh	Denotes the surface runoff which supplies the water input to aquatic ecosystems accompanied with pesticides
	Water resource conflicts	Zpc	Represent disagreement cause by water development activities
River basin management (agent)	Buffer zones of toquilla straw plant	Zlh	Describe the employment of toquilla straw plant as agricultural practices
	River basin practices	Zlh	Refer to the human actions to protect and manage water resource

3.2.3. Model fragments

Model fragments describe chunks of knowledge that may apply to scenarios (*Bredeweg et al, 2007a*). The library of model fragments (MF) from Chaguana basin involves static, process and agent model fragments, which were created in Garp3. Most of the MFs are shown in the following subsections.

3.2.3.1. Static fragments

Static fragments are used to describe parts of the structure of the system, and the proportionalities that exist between the quantities (*Bredeweg et al, 2009*). The Chaguana basin model consists of 24 static fragments which are explained further on.

The contaminants which contribute to alter the water quality are represented through the MF *Pollutants configuration*. The entity *River* and three quantities: *Nutrients*, *Heavy metals* and *Pesticides*; are introduced as conditionals meaning that only appear in the simulation when explicitly mentioned in the scenario.

Macroinvertebrates (mi) play a key function in stream ecosystems and are used as indicators of watershed health. Therefore, it is introduced by its entity and one quantity *Population density* (Figure 3-5).

Population is a MF in which the model fragment *Macroinvertebrates population* comes again (represented by green color) indicating its parent model fragment and content. *Population density* has two proportionalities (P+) with *Birth* and *Mortality*, representing the feedback mechanism (changes in *Population density* propagate to changes in *Birth* and *Mortality*, in the same direction) (Figure 3-5).

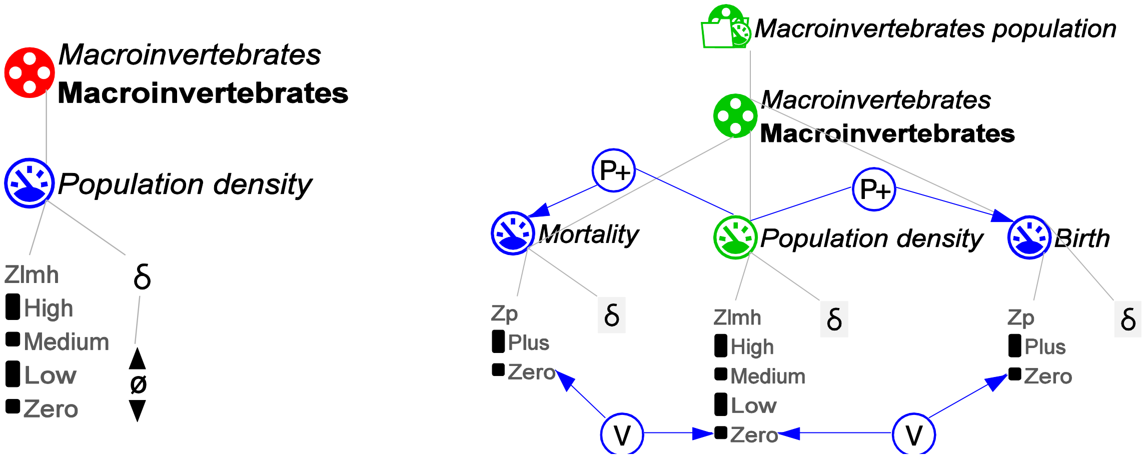


Figure 3-5 Static model fragment 'Macroinvertebrates population' and Static model fragment 'Population'(from left to right)

The *Macroinvertebrates population* static MF has two children or subtypes (Figure 3-6). When the latter fragment is active, *Mi density* and *Mi non density* are implemented. The idea is to enable these two situations by the simulator.

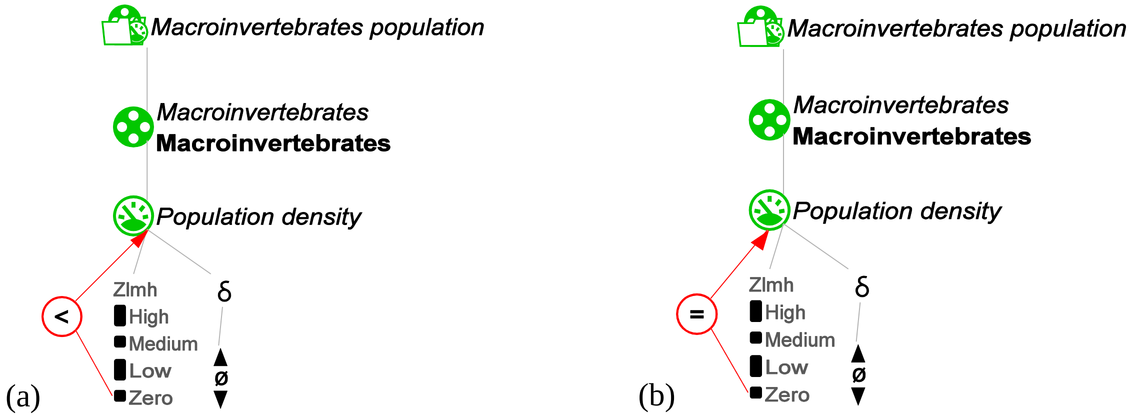


Figure 3-6 Static model fragments 'Mi density' (a) and 'Mi non density' (b)

The relation between the riverine vegetation and existence of vegetation near side of the river is meant by this MF (Figure 3-7). It describes how *Degradation* (with negative influence) and *Regeneration* (with a positive influence) is triggered by the *Vegetation presence*. Vegetation presence should be greater than zero as a condition for these quantities to exist. The MF Vegetation presence in the river was constructed based on one model fragment from Riacho Fundo model by Salles and Bredeweg (2009).

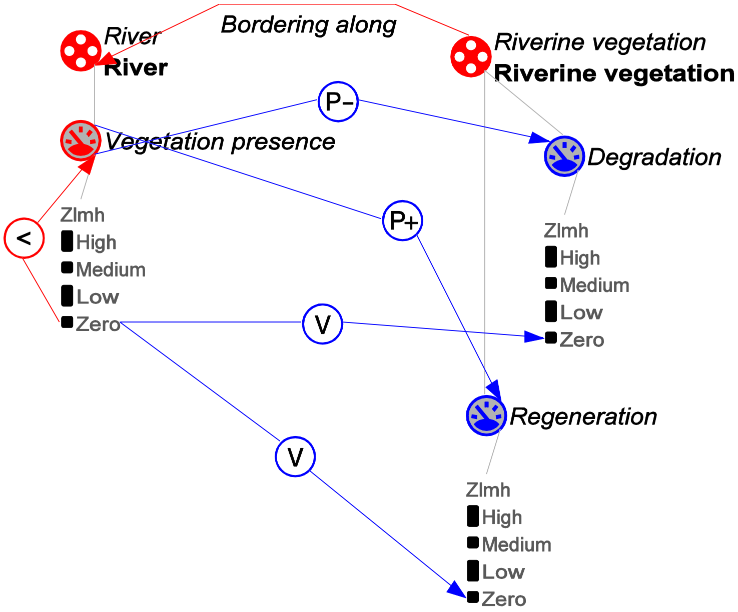


Figure 3-7 Static model fragment 'Vegetation presence in river'

The MF *Vegetation growth* is added as condition in the static fragment *Habitat quality*. Relations between *Habitat quality* and *Vegetation presence* are represented in this MF. The influence of the former on the last one is represented by a positive proportionality: P+ (Habitat quality, Vegetation presence). Notice that only relevant information is presented in Figure 3-8.

The *Macroinvertebrates* and *River*, as shown in Figure 3-8, exhibits the structural "Live in" and specifies a positive proportionality (P+) between the quantities *Habitat quality* and *Birth* representing an indirect causal relationship.

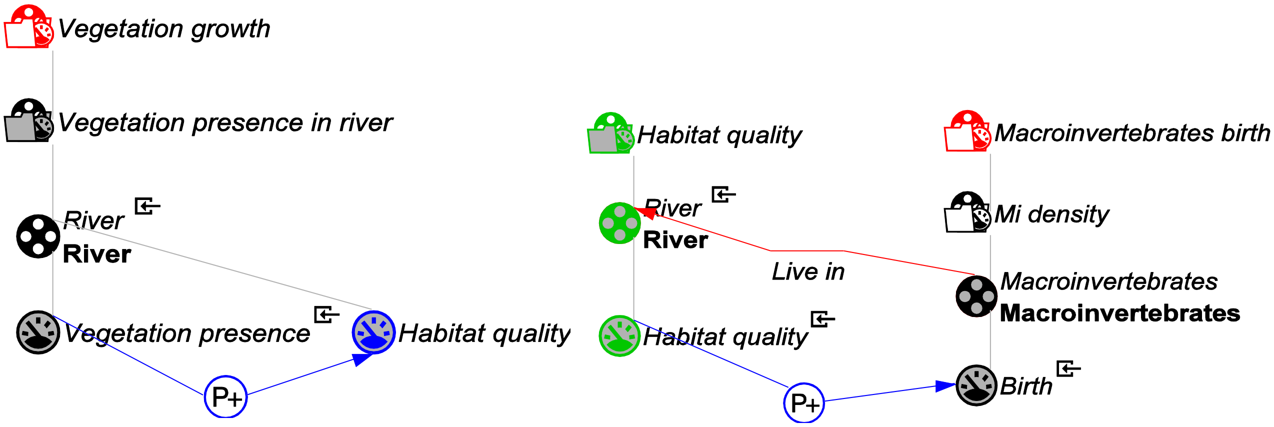


Figure 3-8 Model fragment 'Habitat quality' and 'Habitat quality influence on mi' (from left to right)

This MF shows the influence of *Stressor factor* on *Mortality* (Figure 3-9). The former one is set conditional and only appears in the simulation when it is explicitly mentioned in the scenario.

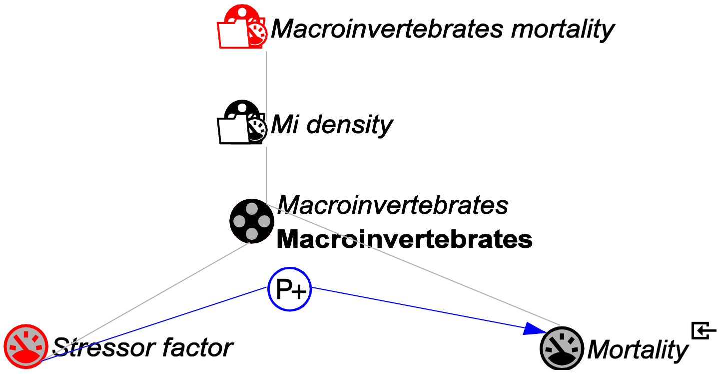


Figure 3-9 Static model fragment 'Stressor factor for mi'

If the *Agriculture runoff* of banana farms increases, the *Pesticides runoff* and *Nutrients runoff* also increases, this notion is represented with P+ relation (Figure 3-10).

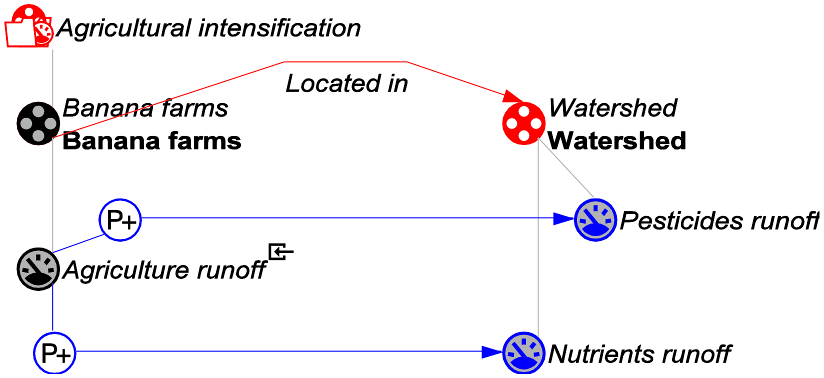


Figure 3-10 Model fragment 'Watershed runoff'

The *Watershed runoff* static MF encompasses two subtypes. To construct the *Nutrients runoff* MF, one model fragment is imported as condition (*Pollutants configuration*). The quantities *Nutrients* runoff and Pesticides runoff contributes proportionally positive (P+) to *Nutrients* and *Pesticides* respectively in the entity *River*. In the case of Figure 3-11a, correspondence dependencies (Q, dQ) is used between their quantities values and derivatives; showing a strong dependency relationship among these quantities. On the other hand, in Figure 3-11b, a value correspondence is used meaning that if *Pesticides runoff* is zero, *Pesticides* is also zero.

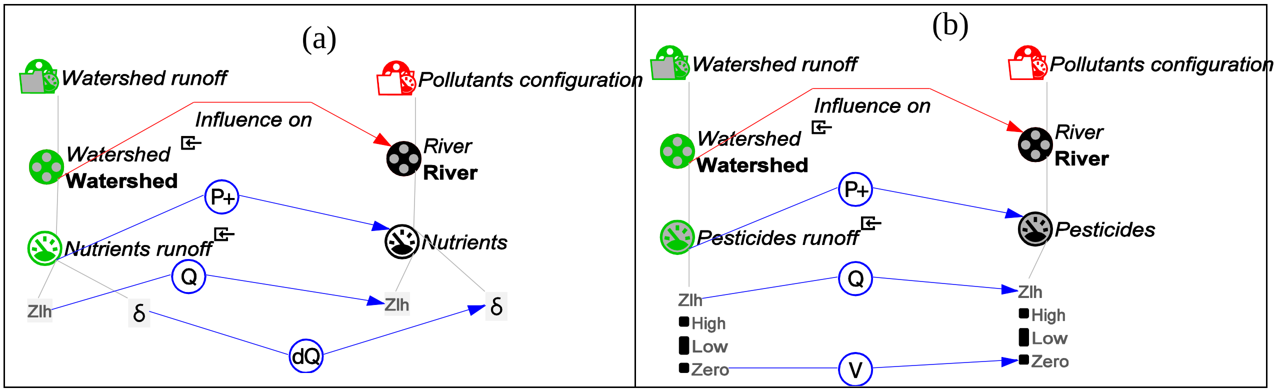


Figure 3-11 Static model fragments 'Nutrients runoff' (a) and 'Pesticides runoff' (b)

Impoundment, embankment and canalization of water bodies are common practices developing in the lowlands by banana farms. These physical modifications are modelled as when *Irrigation activities* increase, the *Degradation* of riverine vegetation also increases, and as a consequence the habitat quality for macroinvertebrates is reduced. This notion is captured by P+ relation (Figure 3-12).

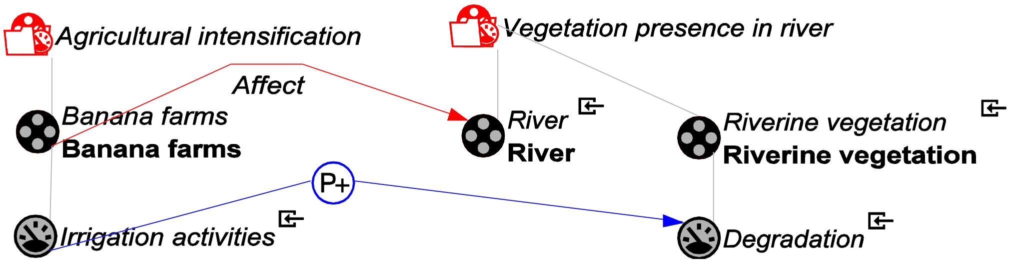


Figure 3-12 Model fragment 'Irrigation influences on riverine vegetation'

Nutrients are defined in the following MFs and include two MF subtypes. MF (a) is used to represent the eutrophic state and thus to determine the high presence of nutrients in the aquatic system. The eutrophication could arise specially at the outlet of the watershed where the stream current is slow-moving. The quantity *Nutrients* is associated with the quantity *Eutrophication* via a positive proportionality. A direct correspondence is implemented in the MF to appeal the eutrophication during the simulation. When *Nutrients* reach the value high, it causes the quantity *Eutrophication* becomes active. The relation Nutrients>Zero is established by means of an inequality in the simulation. Because it is assumed that the load of nutrients is present either with the economic activities or without them.

The MF *Inflow water quality configuration* presents the structure of the water received by the shrimp farms located at the outlet of the watershed. It contains as condition the entity *Shrimp farms* and this entity has as consequence the quantities *Inflow water conservation*, *Inflow water quality deterioration* and *Contaminated flow*.

Water exchange is a frequent practice carried out by the shrimp farms. The quality of fresh water compromises an adequate water resource for others that benefit from the same source. The water pollution from upland is represented in this MF. The quantity *Contaminated flow* should be greater than zero as a condition thus *Inflow water quality deterioration* exits; this is modelled through a positive influence (P+) in Figure 3-13. Note that this MF introduces a directed correspondence between the last quantities mentioned. As a result, it is indicated that the value of *Inflow water quality deterioration* can be inferred. Also, a directed value correspondence is implemented indicating if *Contaminated flow* is equal to zero, then *Inflow water quality deterioration* is zero too.

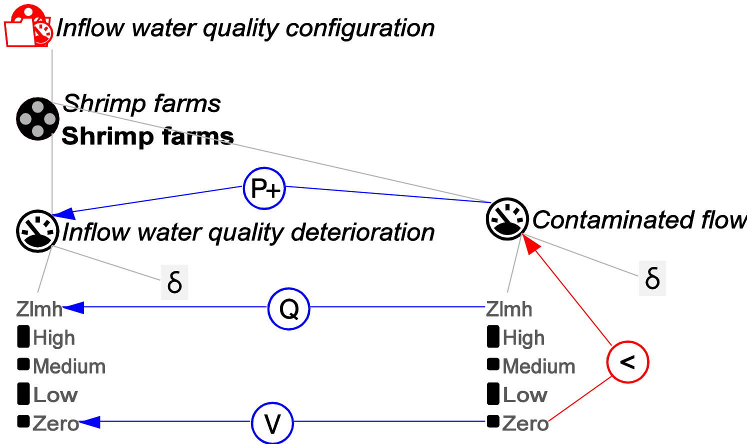


Figure 3-13 Static fragment 'Contaminated flow'

In two different MFs, the entity *Watershed* and *Human settlements* are introduced with the quantities *Water resource conflicts* among the stakeholders and the *Tendency to diseases* of the communities which live in the basin, respectively. Both quantities are presented as conditions.

A conditional assumption label, *Increase in agriculture*, is added in this model fragment (Figure 3-14). This means that this fragment only applies when this assumption is true and therefore it has been defined in the scenario. Additional operating assumptions are exemplified in Figure 3-15. On the other hand, to reduce the simulation complexity, the MF has been also created.

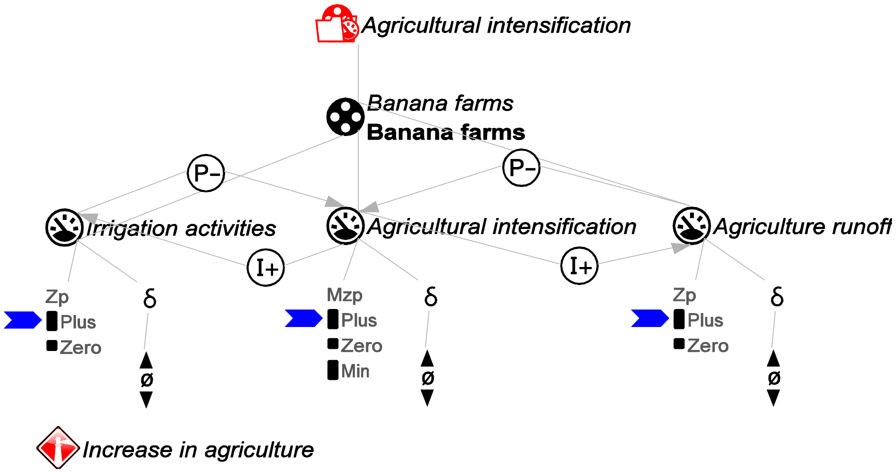


Figure 3-14 Static model fragment 'Increase agricultural intensification'

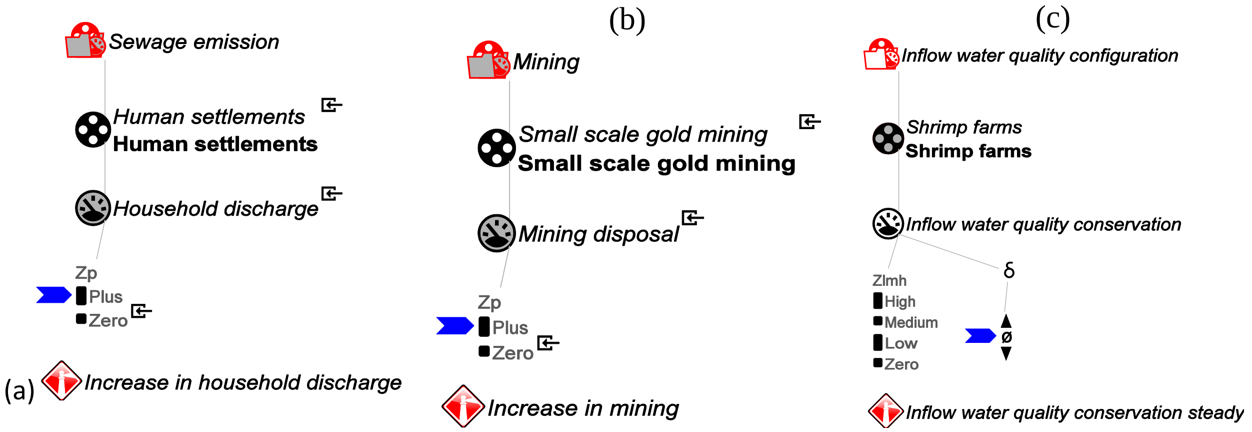


Figure 3-15 Static model fragment 'Increase in household discharge' (a), 'Increase in mining' (b) and 'Inflow water quality conservation steady' (c)

3.2.3.2. Process fragments

Process fragments are used to describe processes that take place within the system (*Bredeweg et al, 2009*). The Chaguana river basin model comprises 18 process fragments which are described further on.

This MF illustrates the structural relationships between *Agricultural intensification*, *Irrigation activities* and *Agriculture runoff*; which denotes the intensive agriculture in banana farms in lowlands (Figure 3-16).

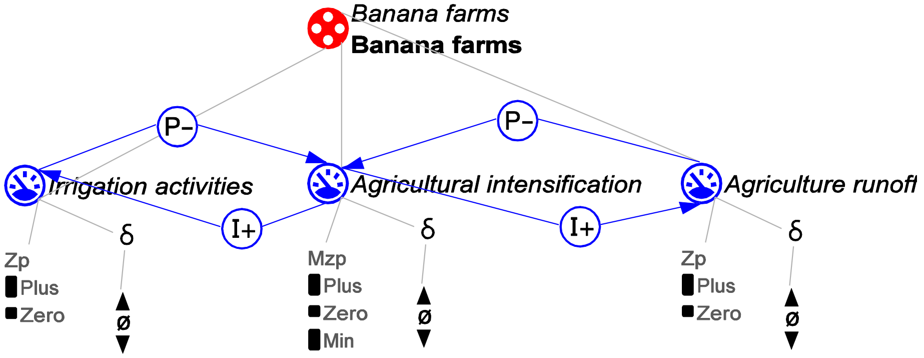


Figure 3-16 Model fragment 'Agricultural intensification'

This process MF describes *Sewage waste* as an effect of *Household discharge*, which itself negatively influences the latter one. A direct correspondence (v) is employed between the magnitude zero of the quantities *Household discharge* and *Sewage waste*, specifying the idea that in the case of non-existing release (*Household discharge*=zero), *Sewage waste* is also zero. Also, a directed correspondence between *Sewage waste* and *Nutrients* is established (Figure 3-17).

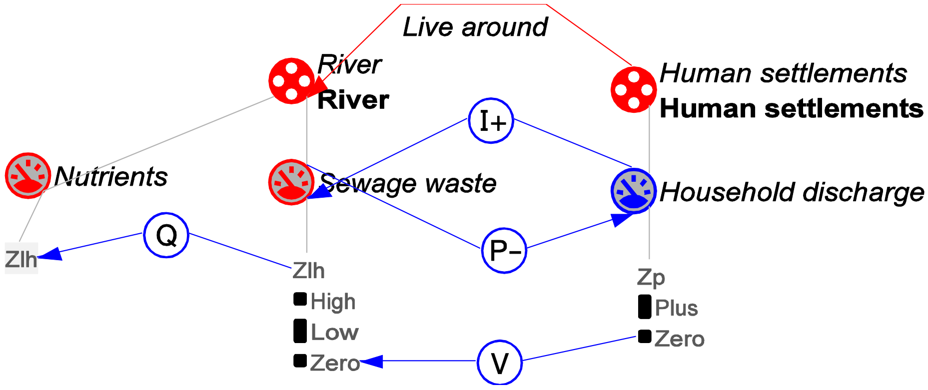


Figure 3-17 Process model fragment 'Sewage emission'

This process MF, shown in Figure 3-18, was constructed by importing the static MF *Vegetation presence in river*. The quantity *Vegetation growth* is added as consequence. The latter results as the difference between *Regeneration* and *Degradation*, it can take three possible values {minus, zero, plus}, where *Regeneration* can be smaller, equal or higher than *Degradation*. The three possible systems conditions are displayed by conditional inequalities thus they do not affect the behaviour of the system (Figure 3-18).

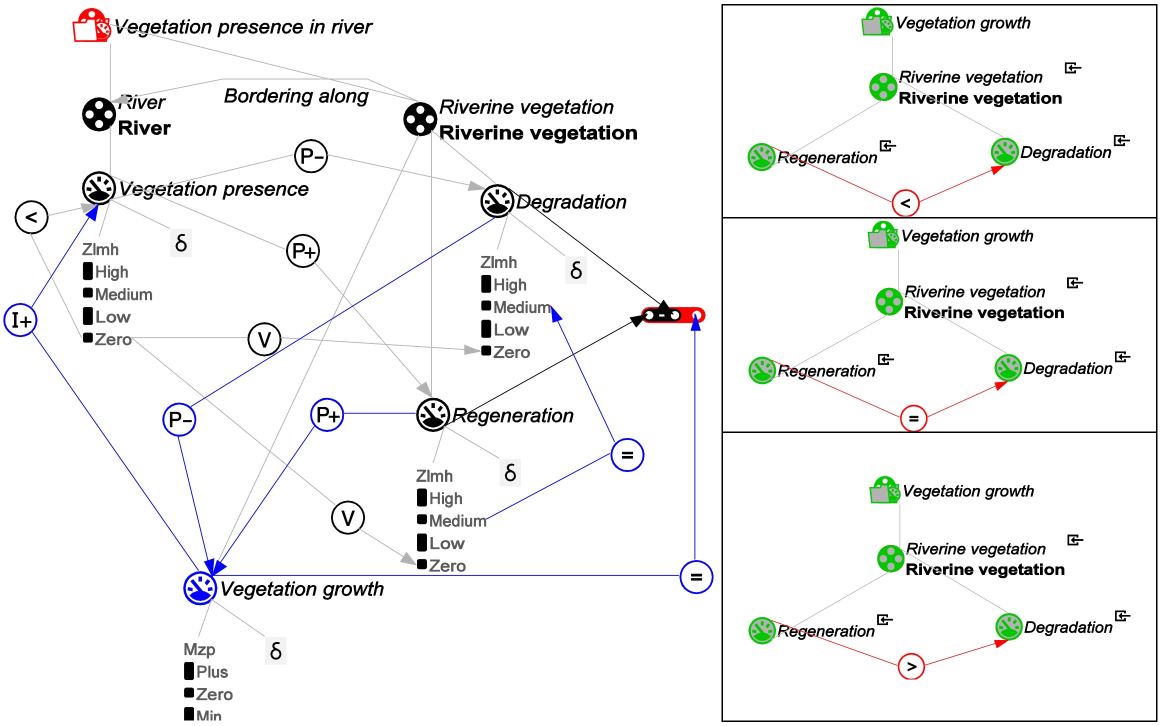


Figure 3-18 Process model fragment 'Vegetation growth' (left side). Children model fragments showing *Regeneration* smaller, equal, and higher than *Degeneration* (from top to bottom)

In order to define the *Pollution load* rate, the model fragment *Pollutants configuration* is imported as condition and the qualitative addition calculus is used to calculate the value of this quantity. At the same time, three qualitative proportionalities (P+) of *Nutrients*, *Heavy metals* and *Pesticides* are related with the quantity *Pollution load* as Figure 3-19 shows.

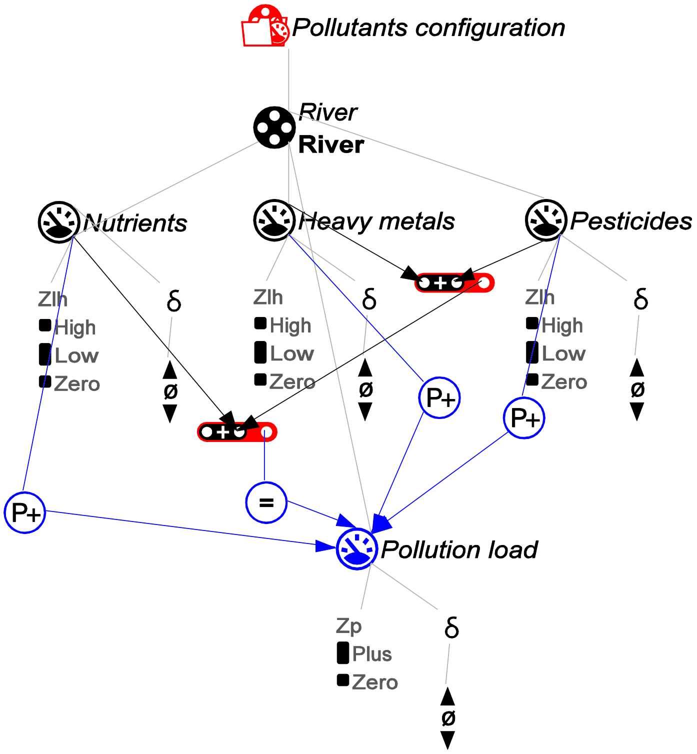


Figure 3-19 Model fragment 'Pollution load'

The next MFs show how *Tendency to diseases*, *Stressor factor* and *Contaminated flow* are influenced by the *Pollution load* rate. The children MFs are presented in the following Figure 3-20.

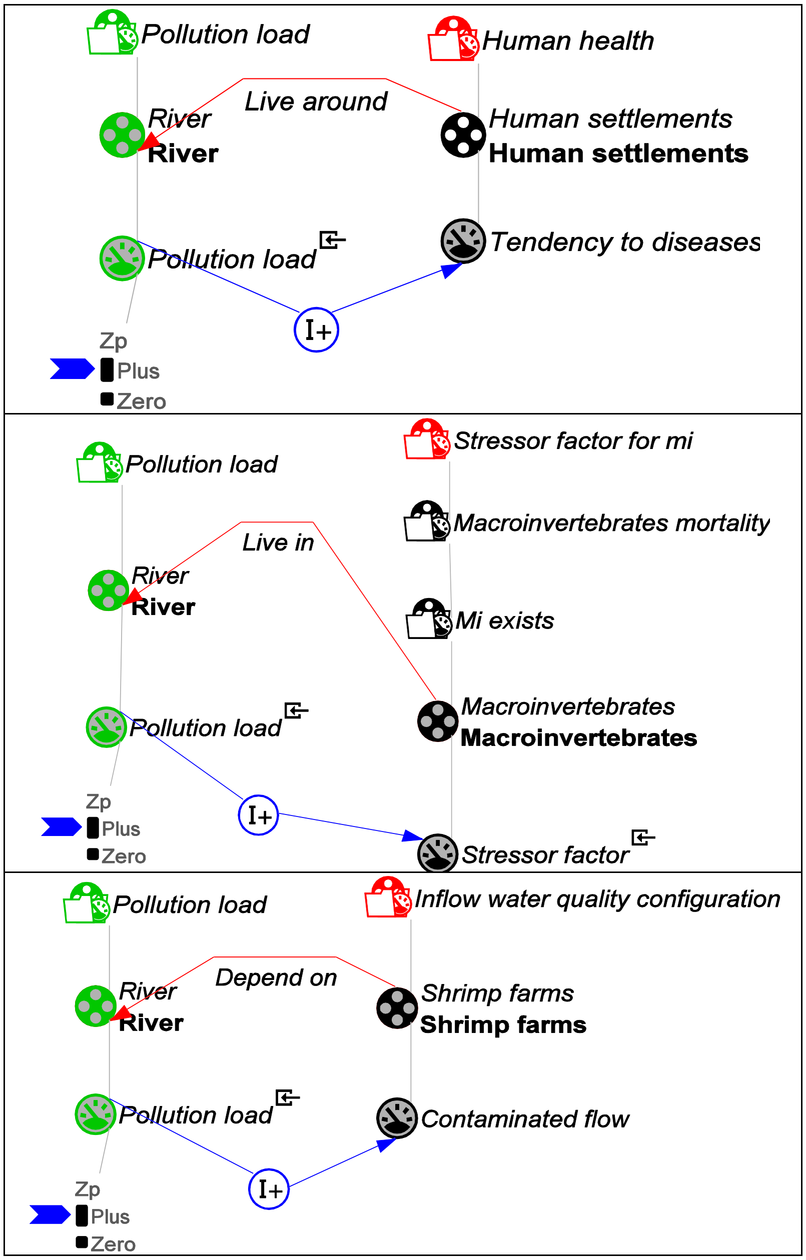


Figure 3-20 Process model fragments 'Pollution load influence on human health', 'Pollution load influence on mi' and 'Pollution load influence on shrimp farms' (from top to bottom)

Inflow water pollution for the shrimp farms is described as a mechanism that considers the *Inflow water quality conservation* and the *Inflow water quality deterioration*. This process MF describes how the *Water resource conflicts* is influenced by the *Inflow water pollution*, the rate of pollution of the used water for the shrimp farms is calculated by the relationship of *Inflow water quality deterioration* to *Inflow water quality conservation* (Figure 3-21). As it was explained for *Vegetation growth* MF, three additional children model fragments were comprised in the library, specifying that *Conservation* is equal, greater and smaller than *Deterioration*. They do not establish new characteristics in the simulation because they only have inequalities as conditions.

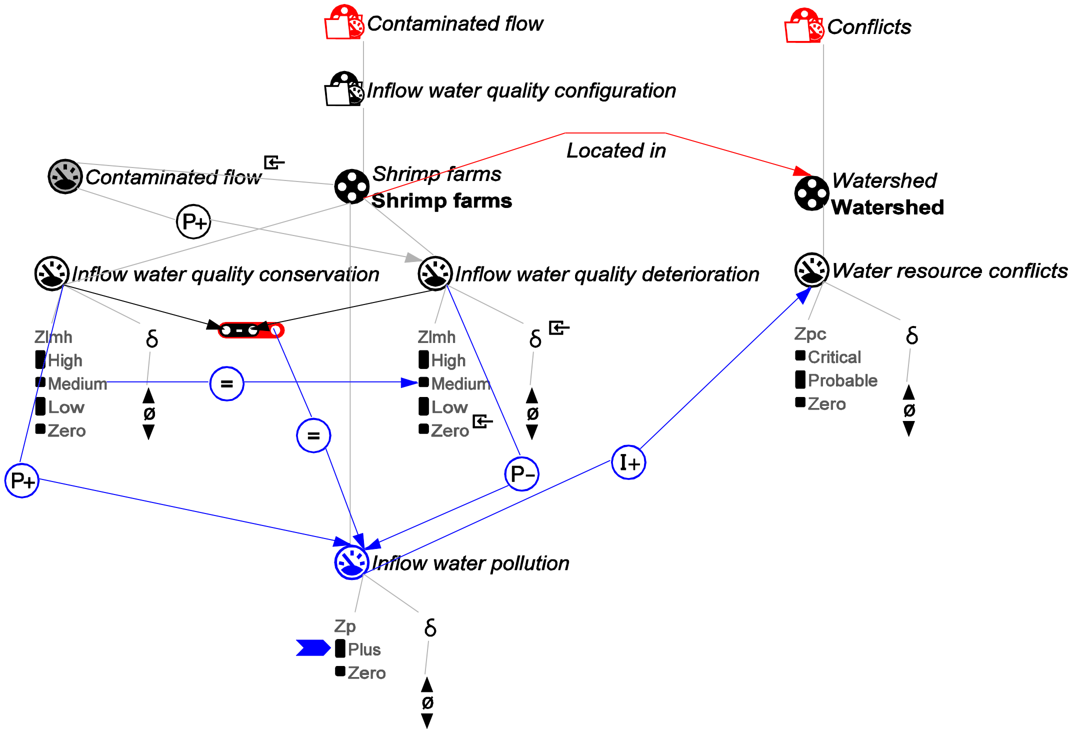


Figure 3-21 Process model fragment 'Inflow water quality'

Birth and *Mortality* (Figure 3-22) rates are measures that determine the *Population density* in these MF, and it is modelled by I+ and I- relations respectively. If there is some *Birth* rate, the amount of *Population density* is going to increase and the opposite happens for *Mortality*.

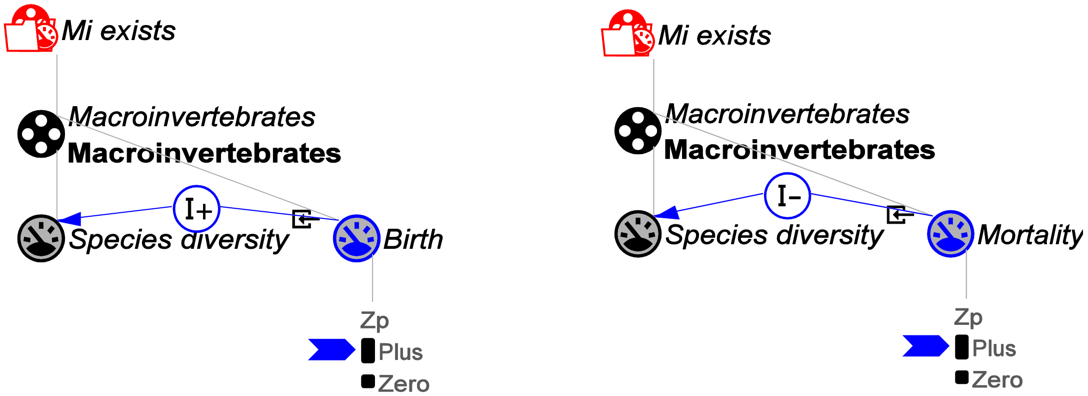


Figure 3-22 Model fragment ' Macroinvertebrates birth' and 'Macroinvertebrates mortality' (from left to right)

3.2.3.3. Agent fragments

Agent fragments contain an agent and may impose one or more influences on the system (*Bredeweg et al, 2009*).

This MF, shown in Figure 3-23, describes the enforcement of *River basin practices*, so that there is a proportionality relation P+ (*Buffer zones of toquilla straw plant, River basin practices*) and a direct correspondence (Q) was used as well. The employment of buffer zones has an influence on *Pesticides runoff* of the watershed. The latter is modelled to be negative proportional to the *Buffer zones of toquilla straw plant*, P- (*Pesticides run off, Buffer zones of toquilla straw plant*).

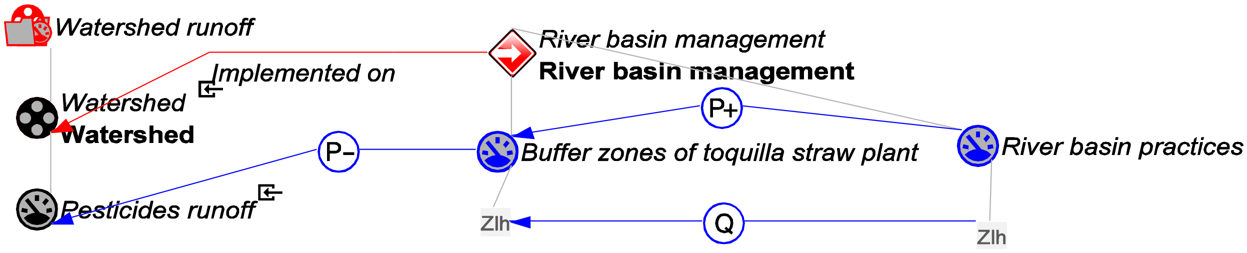


Figure 3-23 Agent model fragment 'Protective zones'

3.3. Model simulations

This section introduces five scenarios and simulation results of the Chaguana basin model. It describes qualitatively some scenarios in the watershed. The general idea is to understand several situations starting from the basic one to complex scenarios where interactions of different entities are implemented. Detailed description of each scenario is specified with the relevant ingredients. In addition, results of the simulation are presented in the following subsections. A general outline of the causal and structural dependencies in the Chaguana basin model is set in Figure 3-39. The global behaviour graphs of scenario#1 and #2 are shown in Appendices as examples.

3.3.1. Scenario #1: Dynamic among biotic components

The first scenario, shown in Figure 3-24, represents the basic behaviour in the river related with the riparian vegetation and macroinvertebrates. This scenario includes eight quantities: *Degradation*, *Regeneration*, *Vegetation presence*, *Habitat quality*, *Mortality*, *Birth*, *Population density* and *Vegetation growth*.

Starting with initial values for *Vegetation presence* and *Population density* = <medium, ?>; *Degradation* = <low, ?>; *Regeneration* = <high, ?>; *Mortality* and *Birth* = <Plus, ?>; and *Habitat quality* <good, ?>, as it is indicated with arrows.

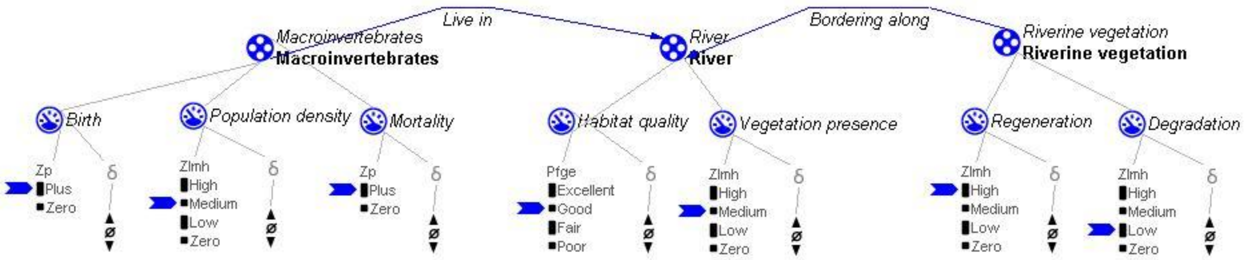


Figure 3-24 Description of scenario#1 indicating system structure and starting values

This scenario generates 13 states in total by full simulation (Figure 3-25). It has five initial states (1, 2, 3, 4 and 5) and two end-states (6 and 10). End state is the limit (either the highest or the lowest) the system can reach it, based on those extreme values the quantities can reach. Thus, an end state show the conditions when a process stops (*Cioaca et al, 2009*). One relevant behaviour path can be [2→8→11→12→13→7→6]. The 6 state ends most of the state paths generated by initial states, except state 1.

Given the initial conditions, from scenario #1, only the state path [1, 9, 10] generated from the initial state 1 leads to have behaviour without macroinvertebrates (*Population density* =zero). On the other hand, the state paths generated from the initial state 2 cause an increasing of macroinvertebrates. A selected behaviour path [2→8→11→12→13→7→6] shows how the effect of the riverine vegetation propagates to the factors considered in this scenario.

It is expected that *Vegetation presence* in river increase up to the high value in state 6. The quantity *Habitat quality* follows the same behaviour and stays in the excellent value afterwards of state 2. Therefore, due to the behaviour of the latter, the *Birth* of macroinvertebrates increases from state 8 to state 6. Initially *Population density* decreases, it becomes stable in state 11 and increases during the rest of the simulation. The quantity *Degradation* keeps the value <Low, Minus>, *Vegetation growth* and *Regeneration* the value <High, Plus> during the whole simulation.

The value history graphs illustrate the behaviour of the system in Figure 3-26. Dependency diagrams from composing relevant model fragments focused on the quantities of state 3 are depicted in Figure 3-27. The current quantity values, magnitudes, and derivatives (black triangle next to the magnitude) are presented in the dependency view.

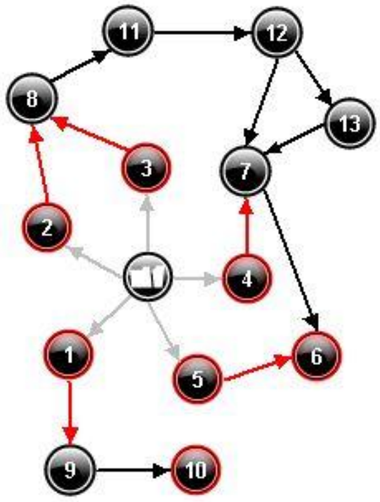


Figure 3-25 Behaviour graph displaying all possible outcomes for scenario #1

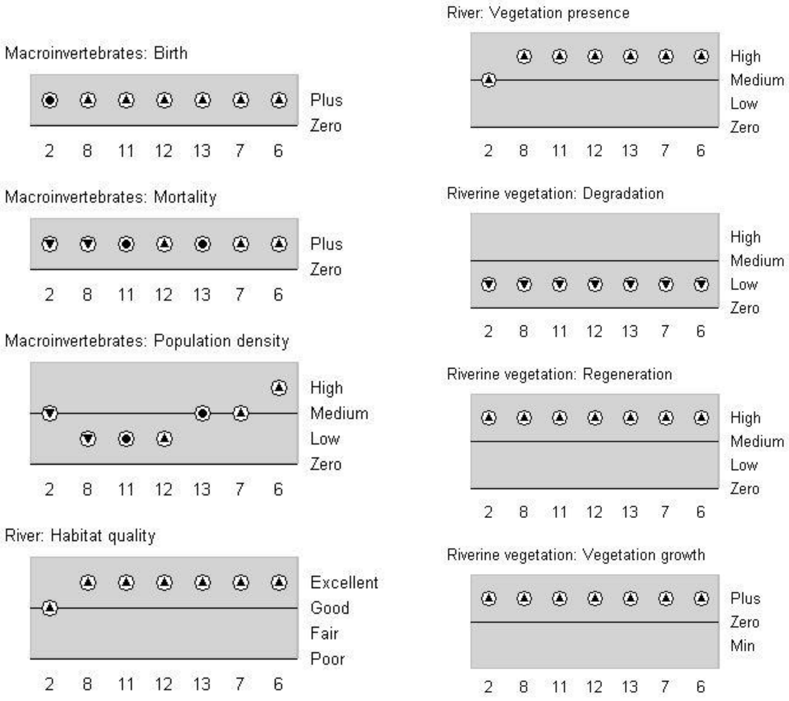


Figure 3-26 Value history view for all quantities of scenario 'Dynamic among biotic components'

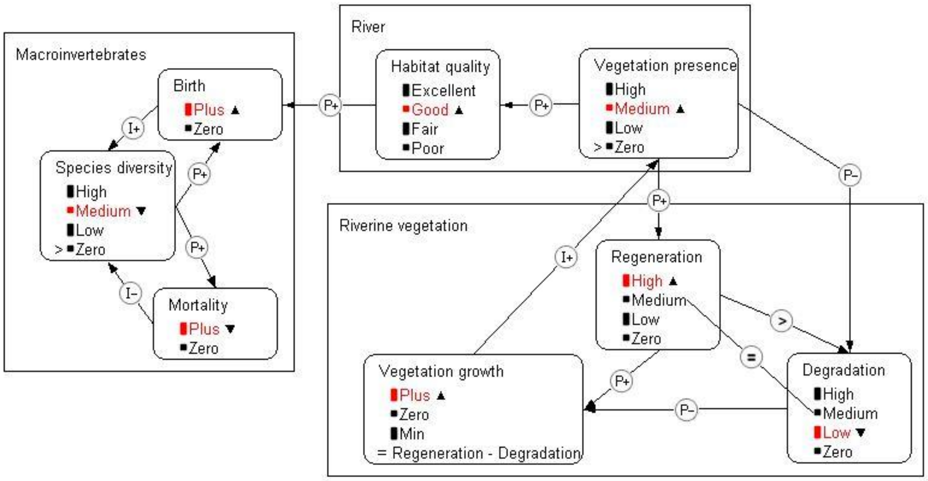


Figure 3-27 Detailed representation of the causal model of scenario 'Dynamic among biotic components' in state 3

3.3.2. Scenario #2: Different sources of pollution

The second scenario, shown in Figure 3-28, describes a system where the river receives different sources of contamination. Most of the quantities are at their *Low* value and *Zero* value of *Tendency of diseases*. *Pollution load* is triggered via calculation of *Heavy metals*, *Nutrients* and *Pesticides*. Simplifying assumptions are used in this scenario in order to make explicit knowledge details are represented in the model fragments (*Salles and Bredeweg, 2009*).

One of the most relevant paths of states is [1, 2, 5, 3]. Figures 3-29 and 3-30 represent the behaviour graph and the value history in which show the quantity values, respectively.

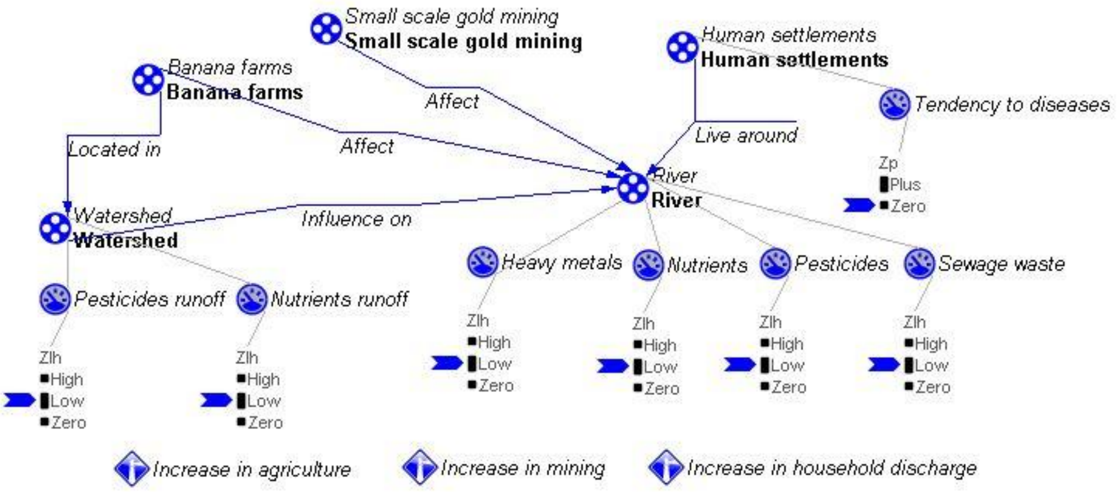


Figure 3-28 Scenario #2 indicating the conditions for quantities in which the main entity is River

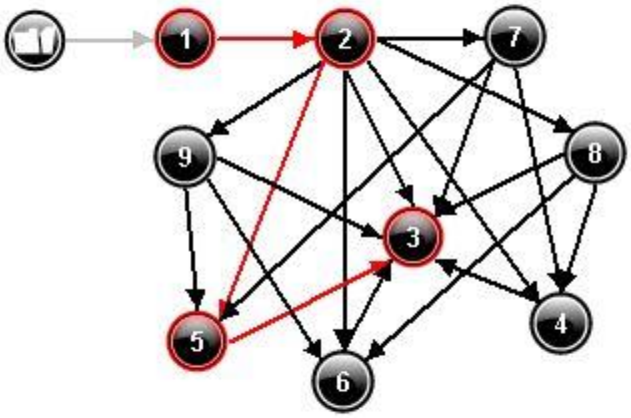


Figure 3-29 Behaviour graph of the simulation#2 showing states and state transitions

On the other hand, processes that are linked with the human activities are active in state 1 from scenario #2. Regarding to agricultural production, *Agricultural runoff* increases and propagates to the quantities *Nutrients runoff* and *Pesticides runoff* increasing the value to <High, Plus>.

Subsequently, the quantities *Heavy metals*, *Nutrients*, *Pesticides* and *Sewage waste* start to increase with a value <Low, Plus> and moves to <High, Plus>. Notice that the quantity *Eutrophication* appears when the quantity *Nutrients* gets a value of High. Finally, in all states *Pollution load* is shown and increasing.

Structure models as presented in scenario #1 and #2, are used to link the abiotic elements with biotic elements and this is what is introduced for the following scenarios.

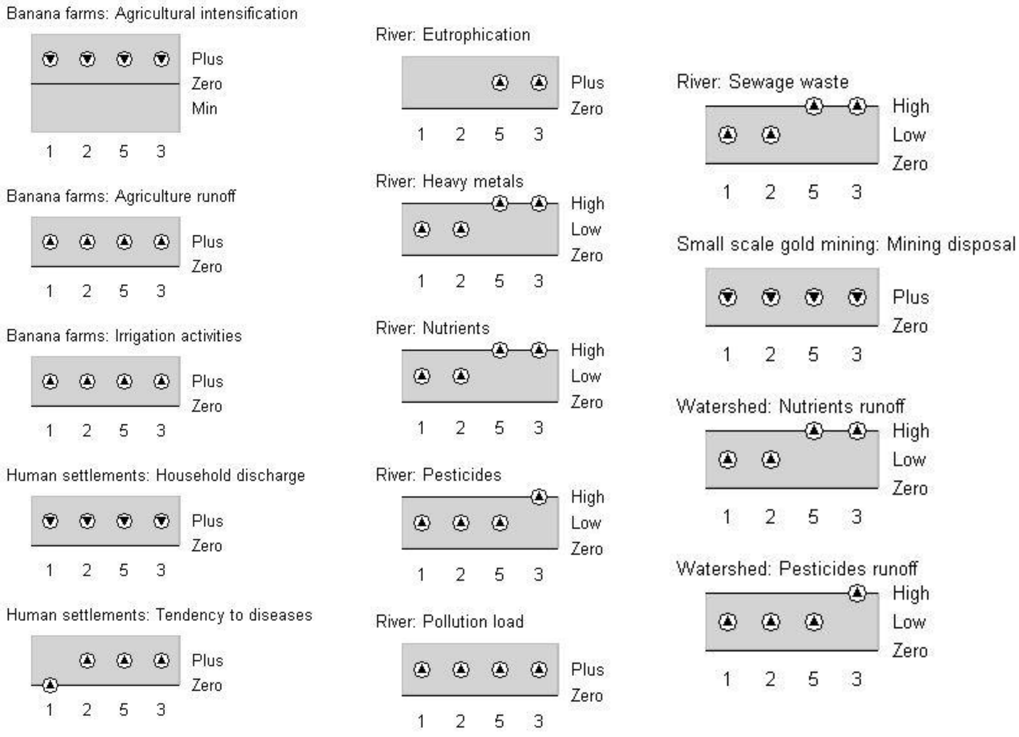


Figure 3-30 Value history for the path [1, 2, 5, 3] for scenario#2

3.3.3. Scenario #3: Biota perspective

This scenario exhibits a similar view of the previous one, but the idea is to explore the burden of pollution on macroinvertebrates and riverine vegetation. Assumptions are used to manage complexity in this scenario. Note that an exogenous feature (*Bredeweg et al., 2007b*), an exclamation mark next to the quantities, was assigned to *Pesticides*, *Nutrients* and *Heavy metals*, in this case constant (Figure 3-31). The important information about this scenario is mentioned in Table 3-5.

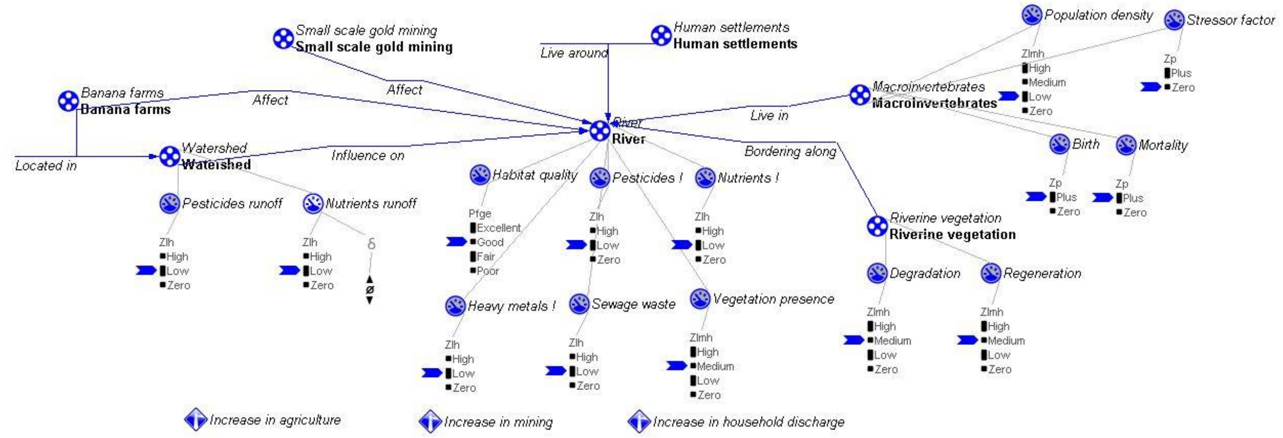


Figure 3-31 Scenario #3 'Biota perspective'

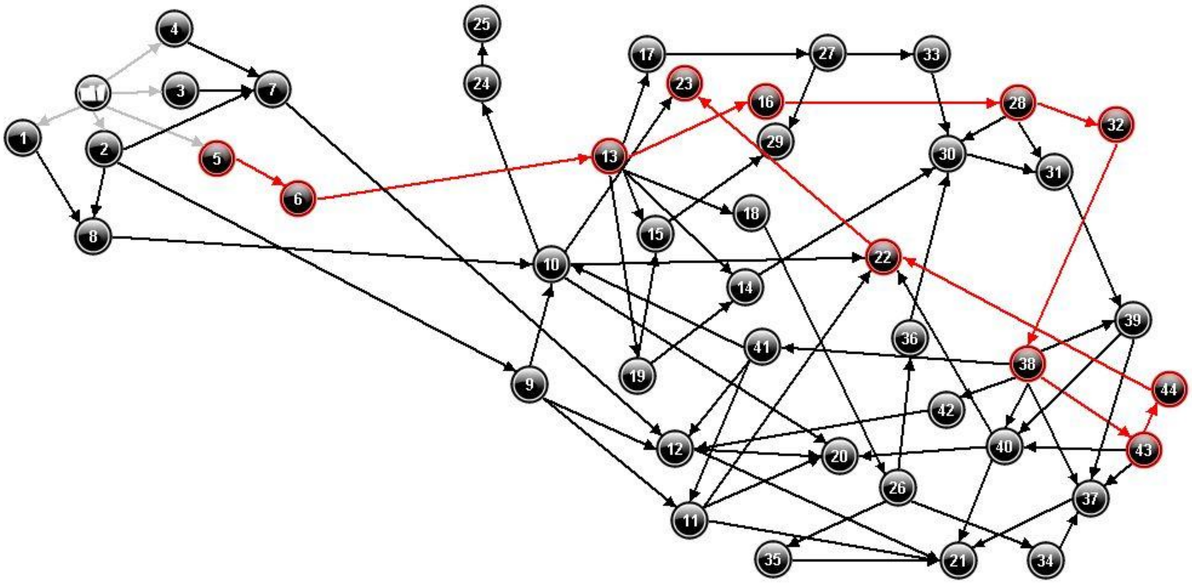


Figure 3-32 State graph of the full simulation of scenario 'Biota perspective'

The simulation of scenario #3 should answer the following question: What is the quality of the basin given the integrated assessment elements provided by the model? The model fragments related with the scenario 'Biota perspective' are addressed in order to emphasize the importance of vegetation for the macroinvertebrates and how agriculture impact on them. In fact, Dominguez (2007) concluded that habitat degradation related to the intensive agricultural activities is probably the main stressor of the riverine macroinvertebrate fauna within the basin.

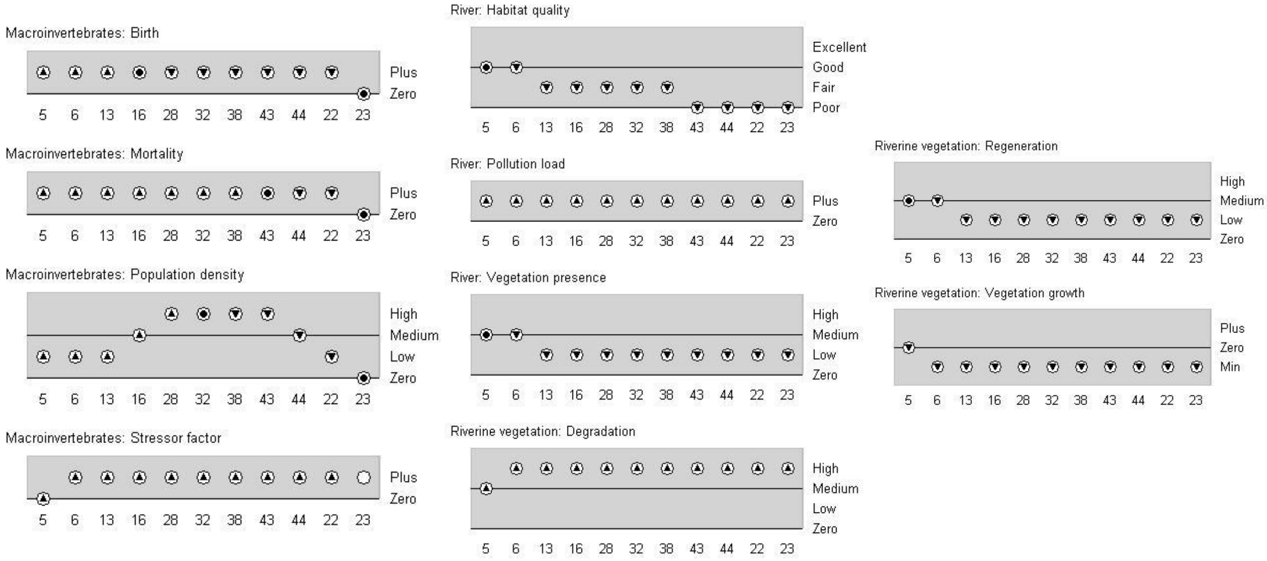


Figure 3-33 Selected quantities of the 'Biota perspective' simulation

In order to see the consequences of the agriculture production and mining processes on the biotic elements, the behaviour path [5, 6, 13, 28, 32, 38, 43, 44, 22, 23] was selected to explore (Figure 3-32). For one side, when *Irrigation activities* become active due to the *Agricultural intensification*, its consequence is propagated. In this case, *Regeneration* and *Degeneration* begin with the same medium value but different direction of change, zero and plus respectively. The former decreases to value <Low, Minus> and the latter goes the opposite <High, Plus>; both keep these values until the end state. Consequently *Vegetation growth* has value <Minus, Minus> during the state 6 to state 23. As a result, *Habitat quality* starts decreasing and reaches the value <Poor, Minus> from state 43 until the end state (see Figure 3-33).

Table 3-5 Simulation summary of scenario #3

Full simulation	44 states
Initial states	[1, 2, 3, 4, 5]
End states	[20, 21, 23, 25, 29]
Relevant behaviour path	[5, 6, 13, 16, 28, 32, 38, 43, 44, 22, 23]

Additionally, the behaviour of the quantities related with *Pollution load* is reflected by the value <Plus, Plus> during the whole simulation. As a consequence, it causes the *Mortality* rate active between states 5 and 38, being <Plus, Plus> the value of its rate. Then goes to stable in state 43, and gets to the value <Zero, Zero> as well as *Birth*; meaning that *Population density* reaches also this value. This scenario illustrates the physical habitat degradation meaning that biotic integrity is being influenced by human burden activities; in this way, the question formulated at the beginning is responded.

3.3.4. Scenario #4: Conflicts perspective

The effects of agriculture and mining in the basin over the shrimp farms can be examined in this scenario (Figure 3-34 and Table 3-6). This scenario introduces the inflow water pollution process. In this scenario, no exogenous behaviour is considered, only the assumption of inflow water quality conservation.

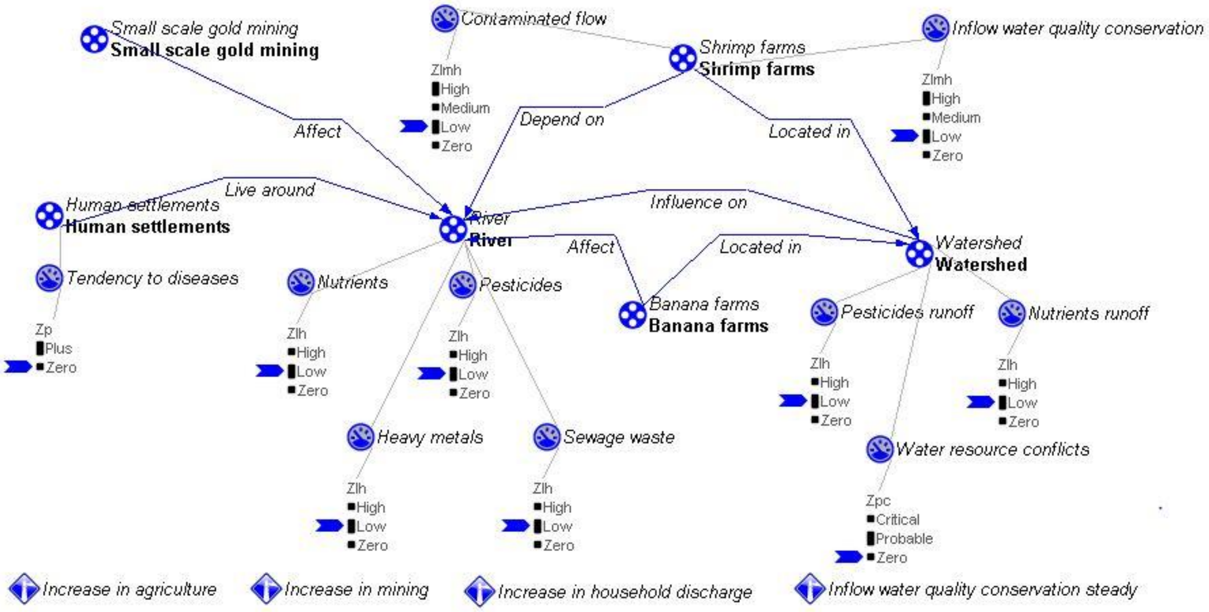


Figure 3-34 Initial scenario for simulating the conflict perspective

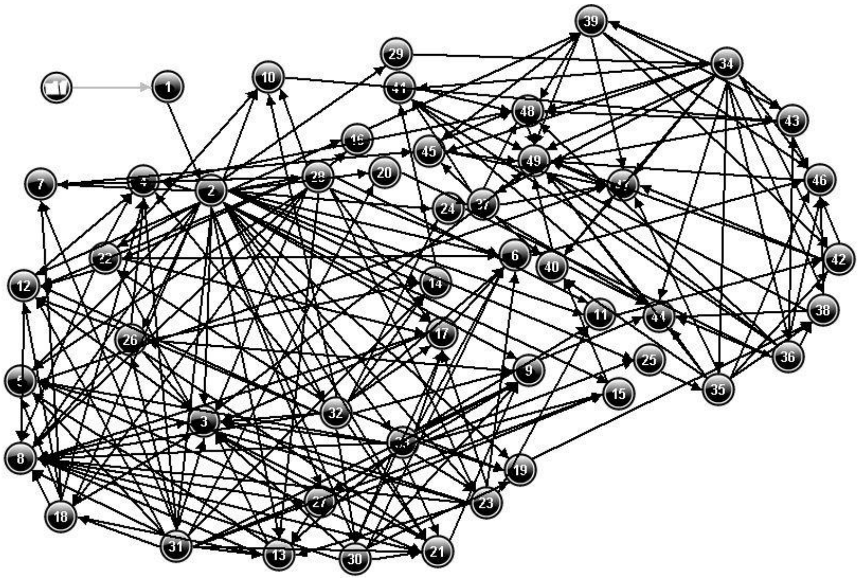
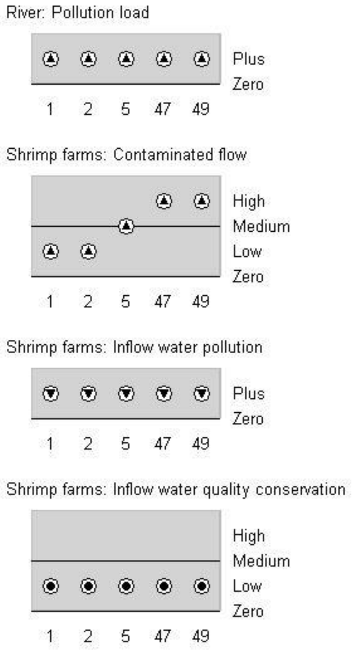


Figure 3-35 Behaviour graph obtained in a simulation starting with scenario #4



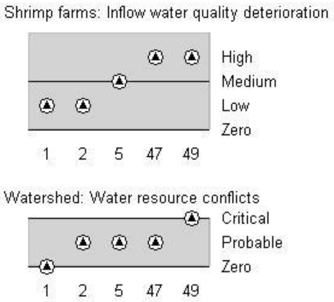


Figure 3-36 Value history for the conflict perspective

Table 3-6 Simulation summary of scenario #4

Full simulation	49 states
Initial states	[1]
End states	[49]
Relevant behaviour path	[1, 2, 5, 47, 49] (Figure 3-35)

The simulation of scenario #4 from the conflict perspective (Figure 3-36) is answering the following question: how changes in upstream water quality affect the interests of downstream stakeholders? The *Pollution load* rate has a value of <Plus, Plus> during the whole simulation. Consequently, the quantity *Contaminated flow* is increasing and moves from <Low, Plus> to <High, Plus> until the last state. As the *Contaminated flow* increases, the *Inflow water quality deterioration* also increases having a negative effect on the *Inflow water pollution* as a resource for aquaculture. Due to the assumption of keeping the *Inflow water quality conservation*, it remains steady and has a Low value, remaining unchanged during the simulation. As a result, *Water resource conflicts* could arise among the stakeholders in the watershed indicated by a value of <Critical, Plus>. Although, the value of the latter remains in the value <Probable, Plus> nearly all the simulation, at the end reaches the highest value. These respond that more pollution in the basin will give negative consequences to aquaculture at the outlet being an important economic activity in the watershed, as well as, agriculture and mining.

Water exchange is a routine labor within the shrimp culture practices. Potential conflicts could arise among the inhabitants of the area, due to diversification of the economic activities in the basin. For example, one case is the Taura syndrome disease in Ecuador. It was thought that this disease was caused by the use of pesticides employed in banana plantations around the shrimp farms in the Taura river basin. Nevertheless, it was proved the syndrome viral etiology. This situation was taken to the courts by the shrimp-farming sector against banana farmers and pesticide importers in 1993 *(Matamoros, 2004)*.

3.3.5. Scenario #5: River basin management

As it was mentioned before, a test scenario was developed to assess the behaviour of buffer zones on pesticides runoff of the watershed, and it is represented as an agent. Scenario #5 is shown as an example here. The simulation includes 20 quantities in this scenario (Figure 3-37 and 3-38) (Table 3-7). The quantity *River basin practices* use exogenous behaviour, which specifies that is not influenced by quantities denoted in the system. In this case, its pattern is 'increasing' which effect in a positive derivative.

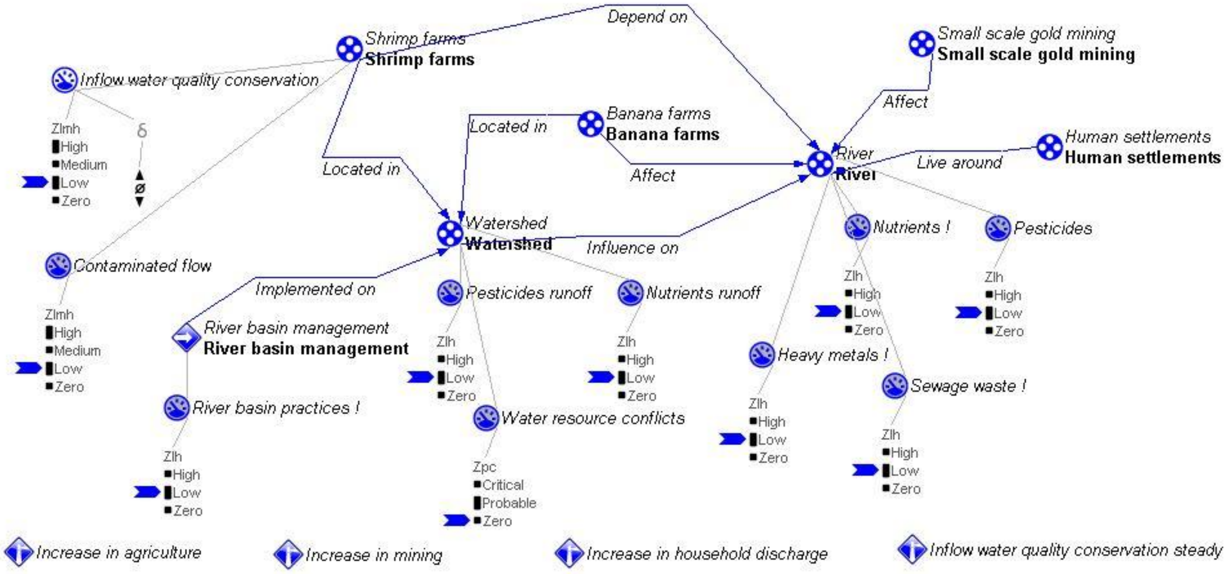


Figure 3-37 'River basin management' scenario

How does interact the river basin management practice against the pesticides disturbances in the watershed? The latter question is answered by the simulation of the last scenario 'River basin management'. Since monitoring of the water resources is limited in the country, protective zone is introduced as an option which may diminish the likely effect of pesticides in the basin. Toquilla straw plants are used as buffer zones, which could be located alongside primary drainage canals and water bodies within banana farms area.

Table 3-7 Simulation summary of scenario #5

Full simulation	67 states
Initial states	[1, 2, 3, 4, 5]
End states	[47, 49, 60, 61, 65]
Relevant behaviour path	[4, 6, 36, 41, 55, 60]

The quantity that drives variations in the system is *Pesticides runoff*, representing the effect received by the buffer zones. As a result, there are five initial states where three of them show a value of <Low, Minus>, one <Low, Zero> and <Low, Plus>. Here, only the path [4, 6, 36, 41, 55, 60] is explained. *Pesticides runoff* starts the simulation with value Low and increases in state 36. Consequences of changing this quantity propagate to *Pollution load*, which in turn influences *Contaminated flow*. Subsequently, the *Inflow water quality deterioration* is strong and dominates the *Inflow water pollution* through a direction of change 'decreasing'.

Although scenario #5 shows the consequences of the implementation of buffer zones, the pollution load rate still remain present because the other pollutants. Different scenarios can be derived from the last perspective in the level of river basin management (i.e. changing the mechanism for handling the exogenous quantity). It is necessary to head towards an integrated water resource management in the country including different types of river basin practices. The main goal should minimize the impact of banana production in water bodies with natural barriers.

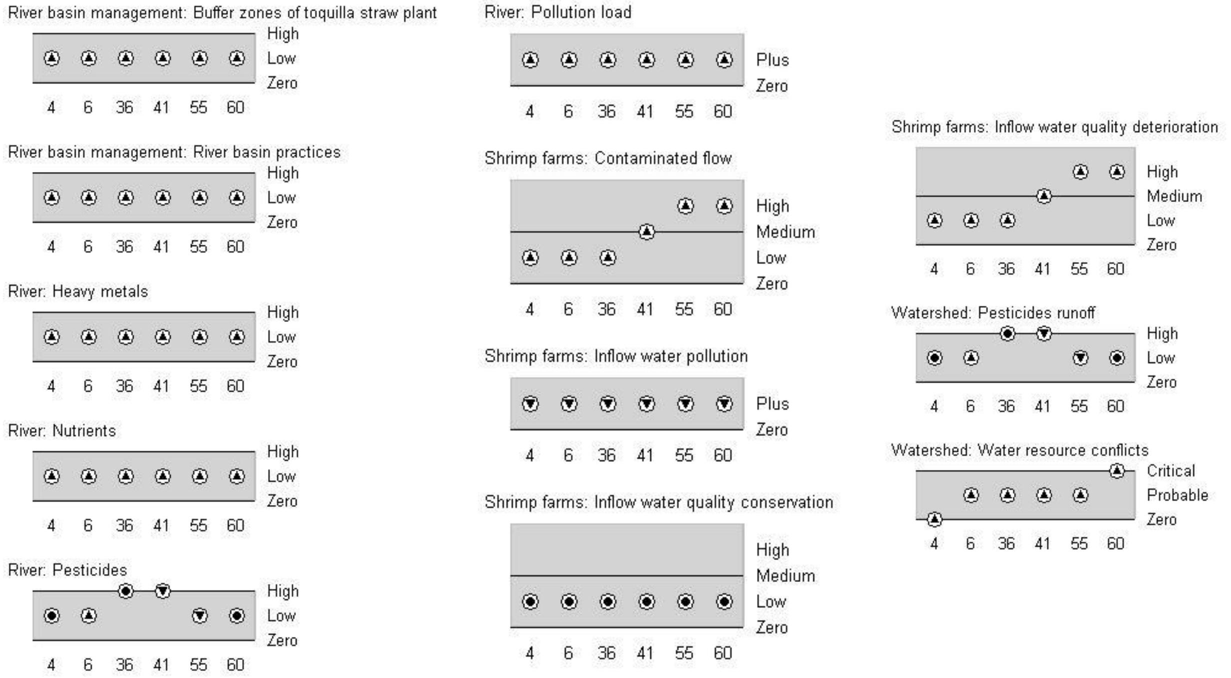


Figure 3-38 Value diagrams showing state path [4, 6, 36, 41, 55, 60] for scenario #5

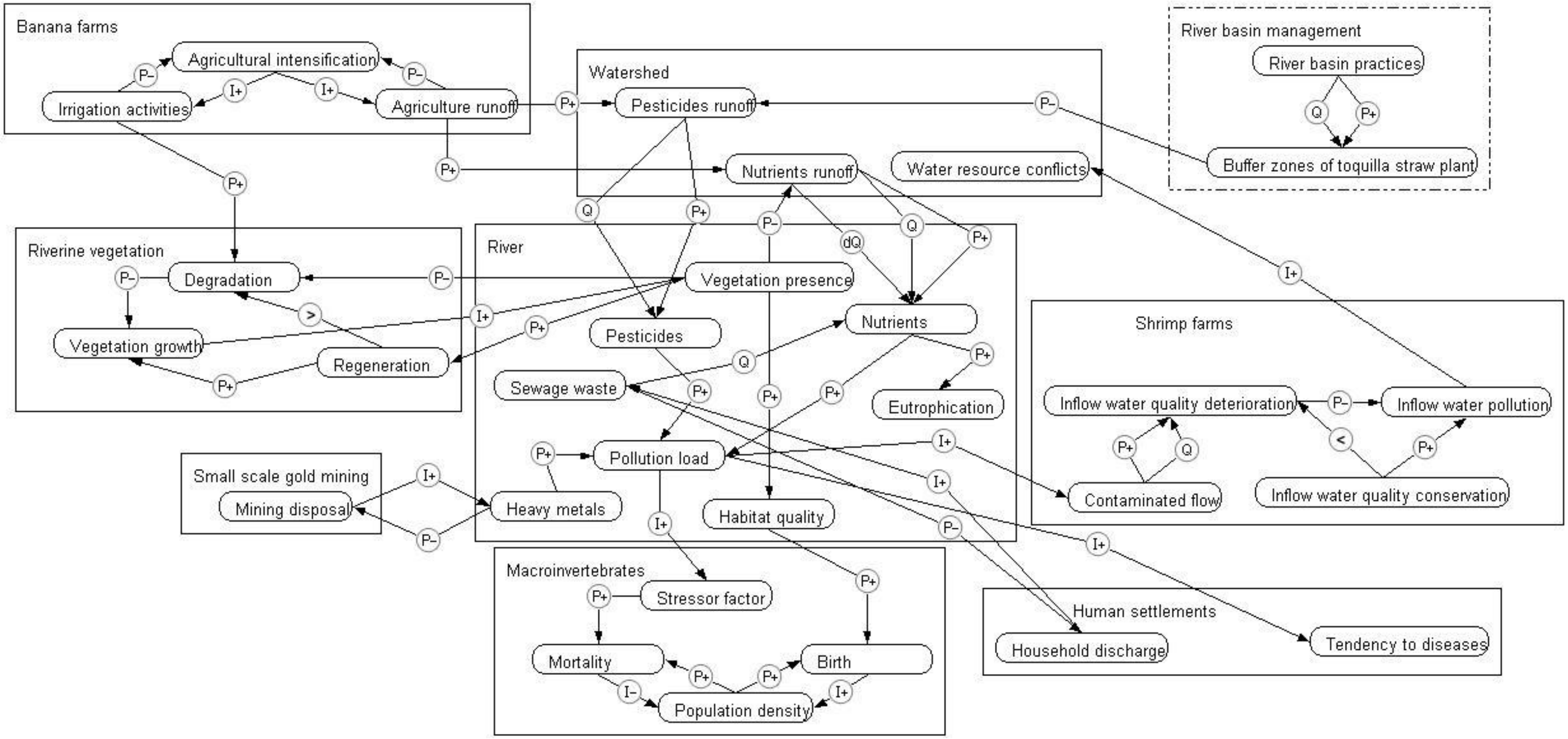


Figure 3-39 Full causal model for the Chaguana basin models. This view was created for illustrative purposes to show all the entities and quantities used in the simulations.

CHAPTER 4: Discussion

4.1. Potentiality and limitations of Qualitative Reasoning

Qualitative reasoning has demonstrated for ecological assessment and forecast. Several researches have demonstrated how useful QR methodology is for ecological applications, especially as an educational and predictive tool. Particularly, for integrated catchment management studies, it could be analyzed based on ecosystem structures and functions with the objective of processing information. That at the same time deals with complex ecological features which have to be related to human needs; it might include economic benefits as mentioned by Zitek et al. (2009).

The main feature is to generate through qualitative models, casual influences that may explain effects or outcomes. The same as stated by Salles et al., (2006) models are useful tools, which perform the role of processes as starting cause of changes and simultaneously how the effects of processes propagate to the rest of the system. The system of structure and functions describes as entities and the interaction between them; whereby it assumes that all changes in the system initiate by processes. Building QR models are constructing partial models or model fragments. These are encoded pieces of information to be combined according to different specifications giving as outcomes scenarios.

Qualitative reasoning models offer an opportunity to explore potential ecosystem responses to anthropogenic activities (*Tullos and Neumann, 2006*). In this sense, Chaguana basin models express relationships which occur in the watershed framed in Qualitative Reasoning. Simulation results showed a commonsense variation in riverine vegetation and macroinvertebrates as integrated assessment elements which used as biological state indicators in a watershed. Garp3 generates the possible qualitative behaviour paths, given the initial conditions from scenarios and which model fragments are relevant.

The notion of Qualitative Process Theory (*Forbus, 1984*) and compositional modeling (*Falkenhainer and Forbus, 1991*) was explored from the beginning of this work. For instance, the construction of two up to three model fragments and combine them in order to emerge from basic configuration of models. Also, it was a worthwhile training to run small simulations with the intention of obtained expected results.

Conceptual models describe a theory even though in this case serve to analyze the behaviour of a given system. In fact, one potentiality of the qualitative of models is demonstrating the “consequences of what we believe to be true” (*Grimm, 1994*). Therefore, a good model is when it meets the goals for what it has built. If the model presents what expected and has a level of complexity adequate for the intended use, then model is suitable.

Through this study, it demonstrated that qualitative analysis gives different choice and productive ways for ecological sciences to be able to develop, categorize and put into practice models. It showed a qualitative theory using it to capture and simulate commonsense theories regarding to population and community ecology. On this case, the commonsense knowledge framed concerning to the description of the basin and fundamental principles of the general theory of ecology. Therefore, the structural models support for this theory.

Structural models or simulation models called by Wissel (1992) meant to represent theories which constructed in order to provide an understanding that concentrated on a purpose and must be kept simple. At the same time, simulation models could be used to describe ecological processes within a system. The main aim is to give a better understanding on ecological systems, in other words, these expose the underlying ecological mechanism and functions. In principle, as it mentioned, it provides an understanding, but if it includes too many details it is possible to end up with an exceedingly complex model without a better understanding giving other significant shortcomings. For these reasons with this study, assumptions are used in order to avoid complexity.

In order to make further explanation of this study's model, it required to determine the type of theoretical problem being addressed as a whole. Following the analogy proposed by Caswell (1988) "models are to theoretical problems as experiments are to empirical problems'' This implicate that using a model as a tool to explain knowledge and theories giving different perspectives and interpretations. It may address new theoretical and empirical problems.

As it discussed above, exploring the consequences of a theory is basically the type of theoretical problem in this study. This gives an option to determine what is possible from theory model that gives a contribution to ecological knowledge. The purpose is to address the theoretical problem, giving a better understanding of function and mechanism as a whole related to ecological science.

Additionally, the view of the model as the expression of a theory encompasses the establishment of relationships among theories components through fundamental principles. One of them is the mortality of the organism including causes and consequences (*Scheiner and Willig, 2008*). The challenge is to develop an integrated theory composed by relationships among them within the determined framework from the theory as a whole. It is pertinent to mention that general theories do not make predictions; rather, they are able to contribute with components assembled and integrated in a theory. At the same time, it could reveal assumptions that are often hidden at the level of models, and it provides interconnections between the components each other.

However, qualitative models often face complexity and ambiguity. The model of Chaguana river basin was not an exception, for example, scenario #3 generated more than 160 states before the implementation of constrains. Assumptions were implemented in order to turn the model for answering the model goals. They also used to reduce uninteresting behaviour (*Guerrin and Dumas, 2001*) and a lack of restricting definitions (*Salles and Bredeweg, 2003; Tullos and Neumann, 2006*). Moreover, ambiguity may highlight where improved knowledge is required

(*Nuttle et al., 2009*). Hence, more modeling effort may contribute further research to develop and expand the understanding of the Chaguana basin behaviour.

In this study, on the other hand, robust modelling practices were followed such as a quantity cannot be influenced by a direct influence (I) and indirect influence (P) at the same time. Adequate establishment of quantity spaces and other behaviour ingredients (e.g. correspondences) were employed, as well. In addition, the using of exogenous quantities (e.g. in scenarios # 3 y 5) provides a certain perspective reducing the number of possible state paths in order to explore other quantity values.

4.2. Related qualitative modelling work

The development of qualitative modelling has been employed in the ecology field during last years. Ecological systems involving population and community dynamics included qualitative models and simulations developed by Salles and Bredeweg (2003). The Chaguana basin models examine the behaviours of the main processes for ecosystem populations (macroinvertebrates and riverine vegetation) in which case are affected by humans.

Likewise, Tullos and Neumann (2006) analyzed the effects of anthropogenic activities in the watershed on benthic macroinvertebrates communities. It focused on the physical habitat stability and trophic shifts. In this work, the definition of relationships between the model fragments allows to interpret mechanistic properties of watersheds activities and riparian vegetation, as well as, the Chaguana basin models.

Alternatively, the contribution of Goulart (2009) described the intensification of farming systems versus conservation of natural landscapes. However, the models of Chaguana river basin only focus on the agriculture as such, leaving the agro-ecological practices aside. In this study, a river basin practice is introduced like an integrated pest management in agriculture. Both cases framed on explicitly causal relations.

4.3. Qualitative models as added value

Monitoring and modelling are the backbones of the integrated river basin management (*Kundzewicz and Hattermann, 2008*). However, monitoring campaigns are not frequent in developing countries like Ecuador, and this make an integrated assessment difficult to achieve. Consequently, qualitative models are added value in the integrated river basin management. The use of models is potentially valuable within the framework for participatory river basin planning of measures. In this case, it has presented as a means to disseminate and understand gathered knowledge of the investigated water resources.

Some of the additional values of models described by Parker et al. (2002), Jakeman and Letcher (2003), and Kundzewicz and Hattermann (2008) are applied in the following paragraphs framed in qualitative reasoning of this study.

A tool for adoption and adaption by stakeholders: monitoring of biological parameters is required in Europe by the Water Framework Directive. Conversely, within the parameters for the preservation of the flora and fauna in surface waters, only include physical-chemical parameters in the Ecuadorian Environmental Law. By means of qualitative modelling, the improvement of an adequate framework for planning of conservation and sustainable management might be accomplished in the country.

A focus for integration across researches and stakeholders: the qualitative models can be seen as a complement of quantitative models. In this sense, works by Matamoros (2004) and Nolivos (2010) could be enhanced in order to describe processes, to identify and characterize water bodies. This study is another contribution to assist for the integrated basin management. As Parker et al. (2002) indicated 'qualitative as well as quantitative elements should be included as an iterative approach is taken to enable the model to evolve with improved understanding of the system under investigation'.

A training and education tool: this is one of the most powerful and widely applied advantages of the Qualitative Reasoning. Under this qualitative methodology, an exploratory tool is shown, which might help to determine conductance nature of a system in a given situation and by which can be transmitted to the policy-makers of a specific environmental issue. Therefore, this approach can deliver expert knowledge available to non-experts for immediate use.

4.4. Evaluation of Chaguana basin model

The simulation models of the Chaguana basin were developed for specific goals, and its evaluation determined according to these objectives. The structured methodology introduced by Bredeweg *et al* (2007a) was followed in the development process of the simulation models. This framework was accomplished to represent the intended ecological situation correctly. Consequently, the computerized model verification was carried out throughout the progress of the model by means of Garp3.

Furthermore, the model evaluation was supplied with the participation of experts. They were provided of the related information; thus, they could have a general understanding of the intended objectives established for the Chaguana river basin. The contribution of the experts was conducted concurrently during and after the building of the qualitative models. At the same time, the latter method constitutes a sort of independent verification; becoming a third party to support whether the simulation is valid. The procedures are used in a subjective way, based on the author of this study and the standpoint of the evaluators.

The procedures chosen in this study were animation and traces. First, in the animation, the model's operational behaviour is displayed graphically as the model moves through time (*Sargent, 2008*). Finally, in traces, the behaviour of specific variables is traced to determine if the behaviour is correct and if necessary accuracy is obtained through the model and simulations (*Rykiel, 2008*).

CHAPTER 5: General conclusions

The main objective of this study is to develop and simulate using a qualitative methodology. Ecological components were examined in order to establish relationships for the anthropogenic impacts of the Chaguana basin.

The Chaguana basin models gathered together information about the area and implemented qualitative simulations in the Garp3 qualitative reasoning engine. The qualitative models assessed different scenarios that were interpreted with the purpose of understanding the behaviours of the system. The conceptual knowledge about the watershed was framed into structural models combined with ecosystem population. Two scenarios implemented two perspectives, one related with the biotic features and the other about the interests of the stakeholders. In both standpoints, it is feasible to compare simulation results from changing the initial conditions.

The model goals were responded through the description of the behaviour effect of human burden action in the watershed. Also, relations between integrated assessments elements were established. It can be seen the behaviour of biotic elements when these socioeconomic activities are active after the simulations were run. By means of the qualitative reasoning, an increasing of expertise is attainable when commonsense is available as well as domain theories. Regarding to the evaluation of the model, it would be useful to count on protocols, guidelines or specific procedure to improve this aspect.

Nowadays, increasing of awareness in ecological issues is essential and qualitative modelling could be a powerful tool to do it. It is indispensable to collaborate in education and environmental consciousness at all levels, especially in rural areas such as the Chaguana basin. New projects and plans by the government are being implemented during recent years. One of them is to characterize water quality at strategic points from the use of irrigation water, but the first starting point is the relevant information that allows an assessment of physical, chemical and biological water. At the level of river basin, the collected information should be analyzed through the causality relationship scheme in order to obtain a participatory planning of measures and integrated river basin management.

5.1. Recommendations for further research

Likewise, there are other characteristics which can be examined over the same structure of the system. For instance, although erosion has not been reported in the basin, this process may be added in a qualitatively approach associating with vegetation especially in the area of banana farms where it is likely to occur. This model could be considered as a starting point for other modelling efforts to contribute to the ecological awareness about the situation of the basin.

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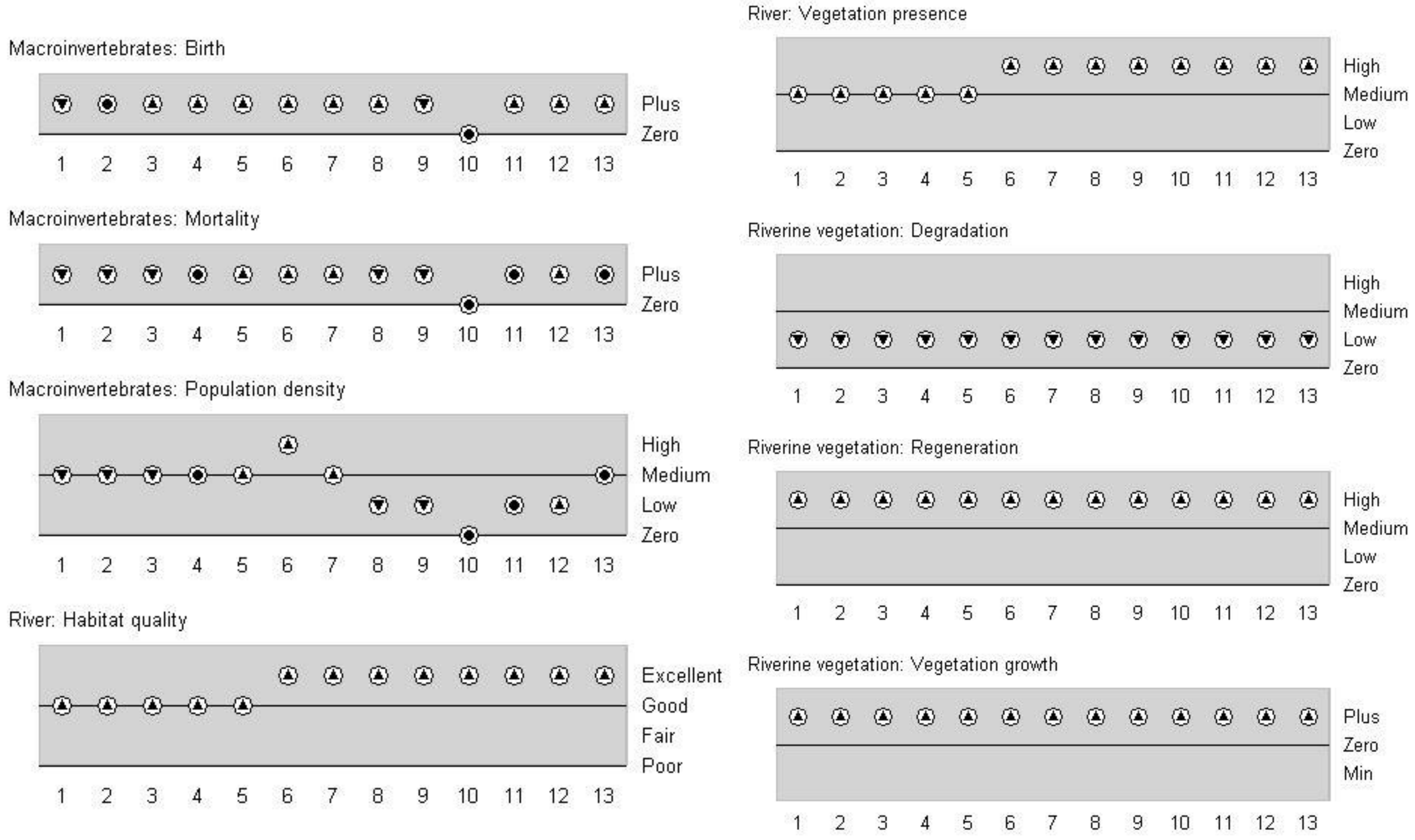
List of Appendices

Appendix 1: Value history view of all quantities in all states generated in the scenario ‘Dynamic among biotic components’



Appendix 2: Value history view of all quantities in all states generated in the scenario ‘Different sources of pollution’