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Instrument: **SPECIFIC TARGETED RESEARCH PROJECT**

Thematic Priority: **SUSTDEV-2004-3.VIII.2.e**

# D6.3.2
# QR models and documentation for learning about sustainable development, focusing on basic biological, physical and chemical processes related to the environment in River Mesta- Bulgaria

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| **Dissemination Level** | | |
| **PU** | Public | |
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## Abstract

Following the standardized Framework for conceptual description of case study (Bredeweg et al., 2005), we are trying to construct QR model representing the behaviour of a stream ecosystem under natural and anthropogenic conditions.
This document represents detailed description of River Mesta qualitative reasoning model. This includes background on the main issues affecting the river and model goals to educate about these issues.
This document represents the final version of a complete qualitative simulation model of River Mesta case study to be used by stakeholders as a learning material about sustainable development.
The document ends with a discussion about how the material can be used in educational contexts and the follow up of present work.

## Document history

| Version | Status | Date | Author |
|---|---|---|---|
| 1 | Draft, initial version. | 1/11/2006 | Elena Nakova Yordan Uzunov Emilia Varadinova |
| 2 | Draft, | 10/12/2006 | Paulo Salles, Elena Nakova |
| 3 | Draft | 20.01.2007 | Tim Nuttle, Elena Nakova |
| 3 | Draft | 205/0211/2006 | Elena Nakova Yordan Uzunov Emilia Varadinova |
| 4 | Final version | 28/03/2006 | Yordan Uzunov, Elena Nakova |

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# Content

# 1 INTRODUCTION

The general objective of NaturNet-Redime project is to support sustainable development by improving knowledge about all aspects of sustainability and provide education mainly about environmental, social and economic tools for implementation of the EU strategy on sustainable development at both EU and international levels.

This document describes an implemented qualitative simulation model about River Mesta case study for the project NaturNet–Redime. Accordingly, the following objectives were set up for this modeling effort:

Develop learning materials (models) for the NaturNet-Redime QR subportal, focusing on physical, chemical and biological processes by integrating available long-term date on the River Mesta for:

- Understanding and forecasting effects of organic pollution and other urban/or industrial pollution on abiotic and biotic structures of ecosystem.

- Understanding and forecasting effects to biodiversity and stream ecosystem structures and functioning, such as phytobenthos, zoobenthos and fish populations as basic biological quality elements;

- Improvement of the river basin planning to support integrated management of the ecological status as demanded by current/modern EU legislation such as WFD 2000/60/EC.

Aquatic ecosystems provide humans with numerous natural services - water supply for drinking, irrigation, industries; energy production; biological resources like fish, etc. Sustainable use of all set of services an ecosystem can provide depends on the ecological status of water bodies – a relative measure for the ecosystem health. Human activities within watershed may substantially change the basic features of a water body, thus causing various disturbances, even destruction of main components and processes that ensure sustainable and long-term existence of the aquatic ecosystems. Worsening the ecosystem health means fewer services that humans can use from water bodies, decreasing total income of goods and benefits, jeopardizing human health and wealth.

A water body is a complex chain of life supporting systems containing many components and processes. Human pressures and impacts on water bodies can change these processes in a negative way. One of the indicative parameters of the ecosystem health is the amount of Dissolved Oxygen (DO). DO is a key and essential parameter for all living organisms in the ecosystem – aquatic animals, plants (both macrophytes and algae), microorganisms; that is why this parameter is considered as an important indicator for ecological status and ecosystem health.

This Deliverable is organized as follows: the entities, configuration and quantities used in the River Mesta model are presented in section 2. In next section we make a detailed description of model fragments. Section 3 shows scenarios and simulations of River Mesta QR model. Finally we make a discussion how this model can be use for educational and practical purposes.

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# 2 Model system

In terms of the Water Framework Directive 2000/60/EC (Annex XIA), the River Mesta (RM) is located in the eco-region 7 (Eastern Balkans). It is a transboundary river shared between Bulgaria and Greece.

Varadinova (2006) described the basic features of the river Mesta. The river Mesta has been intensively studied for the last 35 years due to the heavy organic pollution caused by yeast, cellulose and cardboard manufacturing in the town of Razlog. The industrial wastewater production exceeded 90 000 $m^3$ per day; the average daily levels of $BOD_5$ varied between 300-450 mg $O_2/dm^3$. Such an unfavorable ecological situation remained until 1990, when the operation of the plants – sources of great pollution, was banned by the respective authorities. Immediately, rapid improvements of the water quality and recovery of the affected ecosystem were registered. There have been no significant changes in the flow regime for the last 30 years. Main water use is approached to irrigation of extensive agriculture along the river valley; there are several small hydropower stations on some of the tributaries. Industries in the watershed are in regress for the last 15 years.

The region is recognized as economically under-developed, with high unemployment. Regional development plans focus on intensifying economic activities based mostly on natural features of the region. This includes further development and diversification of tourism; modernizing and intensifying agriculture and forestry; increasing energy production from hydropower; construction of new roads and streets, and enhancing infrastructure like sewage systems, wastewater treatment plants, and domestic waste landfills.

All of these activities need more water than the RM watershed can supply, potentially leading to conflicts between users. State and local authorities are faced with difficult solutions how meet competing demands. Reconciliation of these conflicts requires finding of sustainable solution and appropriate environmental and/or ecosystem health indicators, in addition to the economic and/or social ones, usually taken into account.

# 3 Entities, configuration and quantities

## *3.1 Entities*

Using Garp 3 software we are trying to create a model witch describes River Mesta DO behaviour under different conditions. The entity hierarchy depicted in Figure 1 shows two classes of entities: environment and population.

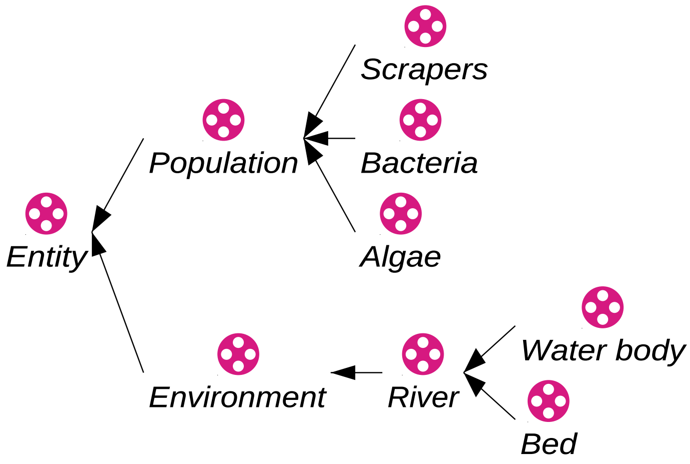



*Figure 1:River Mesta: Entity hierarchy*

A summary description of Entities is presented in Table 1.

Table 1.: Entity summary

| **Entity** | **Description** |
|---|---|
| *River (Stream)* | A natural water body which consists of some amount of running water and river bed/bottom. |
| *Water body* | Part of the stream, a fluid that contains dissolved gases and Substances. Water has its flow/velocity and temperature. |
| *River bed* | The solid background within which the water runs downstream. The bed consists of different types of substrata, the size of particles of which depends on current velocity. |
| *Algae* | A kind of producer. Periphytic algae inhabit (live on) substrata (river bed) |
| *Bacteria* | Reduce the organic substances and bodies of dead organisms. They play important role in self-purification processes. |
| *Scrapers* | A functional feeding group of trophic structure of the macrozoobenthos, which feeds on small-sized organisms like algae and bacteria, scrapping/grazing them from surface of the bottom substrata they used to live on. |

## *3.2 Agents*

All pressures and impacts generated/originated outside a water body are defined as external influences. All external influences are considered to be anthropogenic in their origin. Some of them may cause effects on physical part and another may affect biological part of the modeled system, which is responsible for setting up the oxygen balance in an aquatic environment.

Most of the anthropogenic impacts are related to the human activities within the watershed which could be directly (water use) and indirectly (land use) related to the ecosystem health and ecological status of the system. Three main processes were identified as external agents influencing by some way the amount of DO as an indicator of the ecosystem health and sustainability of the studied river.

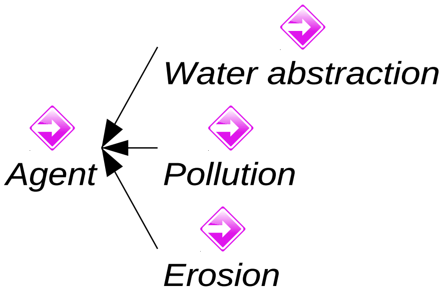



*Figure 2: River Mesta Agent hierarchy*

*Table 2: River Mesta Agent summary*

| Agent | Description |
|---|---|
| *Erosion* | Process of removal of soil particles from upper horizons by precipitation and wind, resulting in reduction of soil fertility and loss of essential nutrients for terrestrial plants. Removed particles entering the water body as suspended solids thus increasing the turbidity and decreasing light conditions necessary for oxygen production by algae. |
| *Pollution* | Pollution is a process of discharging water with extra amount of substances originated outside of water bodies, mostly from households, industries and other human activities in watershed. These extra amount of substances may change significantly the ecological status of a water body and the ecosystem health deteriorating the structure and functioning both physical and biological processes in aquatic ecosystem |
| *Water abstraction* | Humans need water for various purposes of their every-day life and many economic activities. The common practice is water abstraction from water bodies and re-direction of some water amounts through water supply systems for further use by humans. Decreasing water discharge in natural water bodies affects significantly all physical and biological processes which are responsible for setting up the oxygen balance and thus may affect negatively the ecological state and ecosystem health of water bodies downstream the abstraction point |

## *3.3 Configurations*

Figure 3 and 4 depict graphically the structural relationships among entities and agents. These relationships pertain to entities within the River Mesta system.

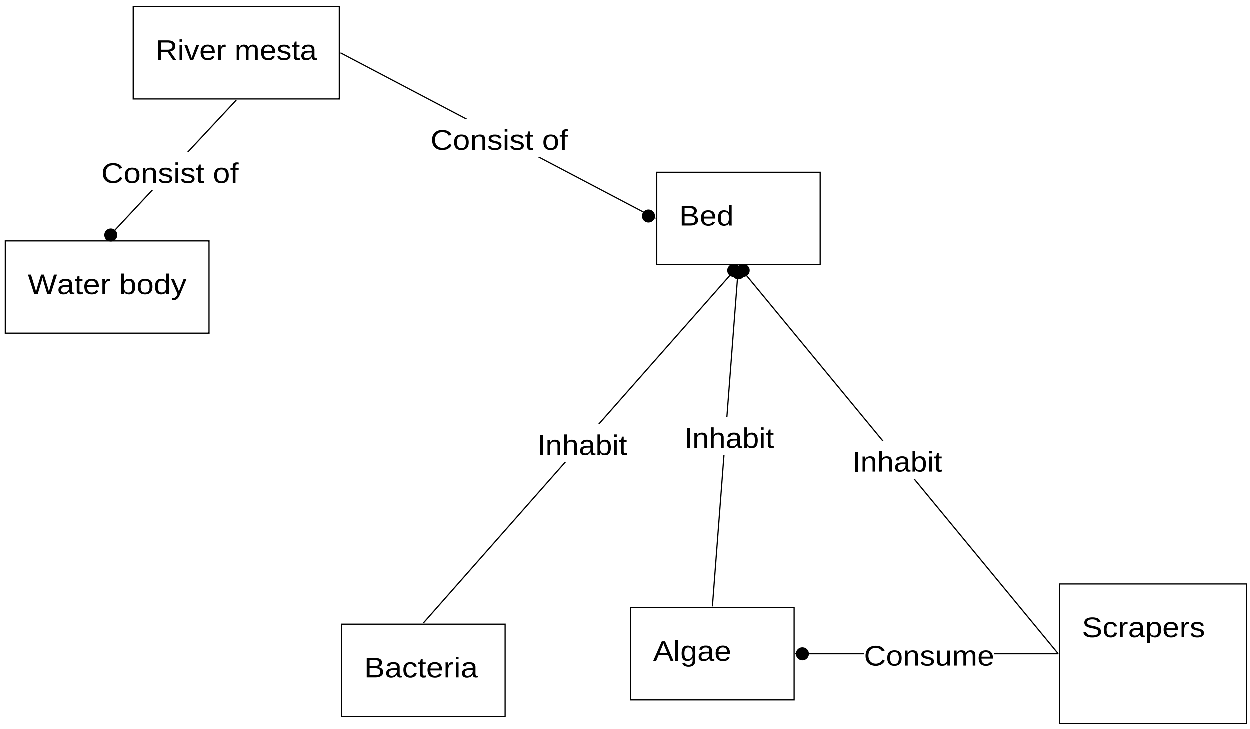



*Figure 3: Entities and configuration used to define the system structure in River Mesta case study model.*

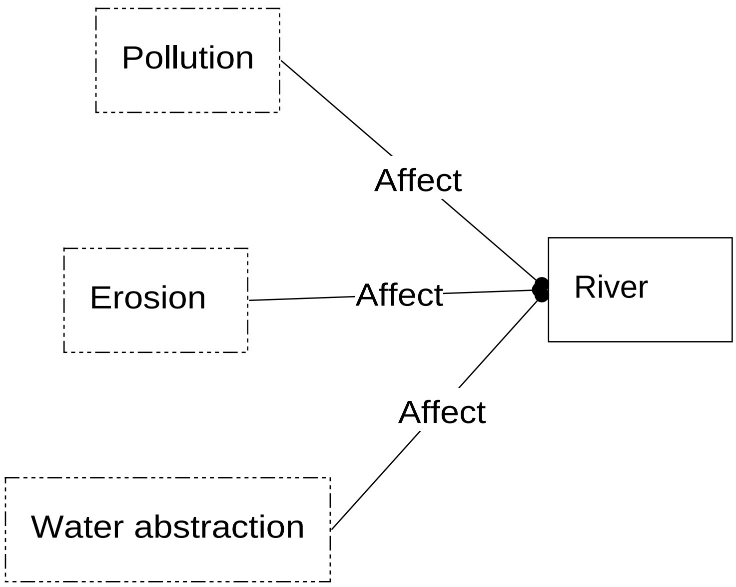



*Figure 4: Entities, Agent and configuration used to define the system structure in River Mesta case study model.*

## 3.4 Assumption

Assumptions are labels which are used to indicate that certain conditions are presumed to be true. They are often used to constrain the possible behaviours of River Mesta model.

Structural assumptions describe certain details in the model, and certain details in extend river stretch in a global behavior step. Then we make a decision which of them to hide and which of them to show.

- The channel morphology (slope, depth and width) is considered to be constant and not changeable (in some extent river stretch), which ensure steady flow/velocity of the Water body without external influence – water abstraction or flood events.

- Steady nutrient and substance availability

- Rate of mortality of aquatic organisms and input of POM from outside the water body are considered to be constant at normal levels that don’t change the stability of the system.

- Temperature is considered to be greater than zero

- Natural level of suspended solids (turbidity) is considered to be constant at normal levels that don’t change stability of the system.

Simplifying assumptions are used to reduce the complexity of the model Figure 5.
There are two type of assumption concerning processes of aeration, diffusion, respiration and photosynthesis. Depending on environmental condition there are cases when aeration is greater than diffusion – when flow/velocity of the river is very fast, and other case when temperature of the water is high, then the reverse diffusion of oxygen on water to the atmosphere is greater than aeration.

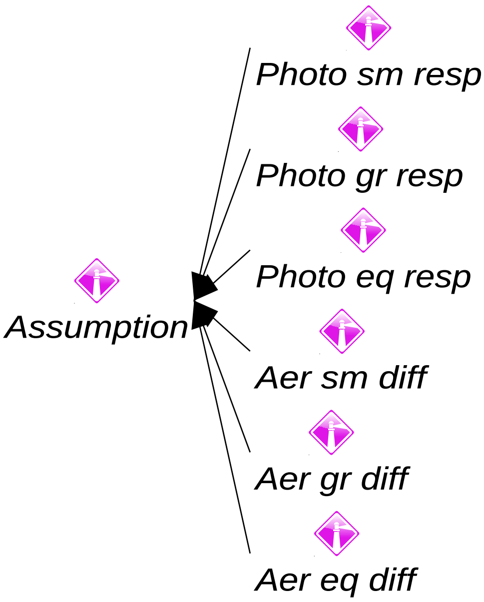



Figure.5:River Mesta QR model: Assumptions hierarchy

## *3.5 Quantities and quantity spaces*

*Table 3: River Mesta QR model: Quantities and Quantity spaces*

| Entities | Quantity | Quantity spaces | Description |
|---|---|---|---|
| **River** ***Water body*** | DO | *Zero, low, medium, high* | Total amount of Dissolved in Water body oxygen. |
| | Aeration | *Zero, low, medium, high* | Additional process to the diffusion of oxygen from air facilitated by the turbulent movement of water masses downstream a river. This turbulence mixes air and water. |
| | Diffusion | *Zero, low, medium, high* | This is process of diffusion of DO into the atmosphere driven by high temperatures. This is a physical law on the dependencies of the amount of DO on the water temperature. |
| | Amount of suspended solids | *Zero, low, medium, high* | Particles suspended in the water, primarily soil particles eroded from land. Suspended solids concentration normally increase with increases in river flow, as a result of scouring of the river bed and banks. High suspended solids loads can cause siltation of the river bed and smother algae and animals, decrease light penetration, cause stress to aquatic organisms and reduce photosynthesis. |
| | Light | *Zero, low, medium, high* | Total amount of light (Radiant energy) that penetrate in water body. |
| | Amount of particulate | *Zero, low, medium, high* | Total amount of particulate organic matter in water body originates from |

| | | | |
|---|---|---|---|
| | organic matter | | dead bodies of living organisms, or from organic pollution ( domestic sewage, urban run-off, industrial (trade) effluents and farm wastes. |
| **River**<br><br>***Water body*** | Diffusion rate | *Minus, zero, plus* | The rate of diffusion – movement of oxygen molecules in to water body or out of him. |
| | Biological oxygen flux | *Minus, zero, plus* | The rate illustrate the balance between the processes of photosynthesis and respiration |
| **River**<br><br>***Population*** | Amount of | *Zero, low, medium, high* | The total amount of organisms in one population. In river Mesta QR models we have tree type of population – algae, bacteria, and scrapers. |
| | Respiration | *Zero, low, medium, high* | Respiration is the process of oxygen consumption when organisms utilize the energy from their food. All aquatic organisms, including producers, consume DO for their respiration |
| **River**<br><br>***Population***<br><br>***Algae*** | Photosynthesis | *Zero, low, medium, high* | The process of production of organic matter for algal bodies and production of free oxygen which is dissolving in water |
| **River**<br><br>***Population***<br><br>***Scrapers*** | Grazing | *Zero, low, medium, high* | Scrapers/Grazers are a functional feeding group of large number invertebrates which feed on while scraping/grazing layer of algae associated to the bottom substrata particles |
| | Consumption rate | *Zero, plus* | The rate of consumption of grazers depending of amount of grazer's population and their available food |
| **River**<br><br>***Population***<br><br>***Bacteria*** | Decomposition | *Zero, low, medium, high* | Bacterial decomposition is a process of degradation of organic matter originated from dead bodies of aquatic organisms and inputs from watershed and pollution. This self-purification requires sufficient concentrations of oxygen and involves the breakdown of complex organic molecules into simple inorganic molecules. |
| | Decomposition rate | *Zero, plus* | The rate of decomposition realized by bacterial degradation |

| Agent | Quantity | Quantity spaces | Description |
|---|---|---|---|
| **Erosion** | Erosion active agent | *Zero, plus* | *Rate of the process that destroy the soil by rain, water runoff and wind* |
| **Pollution** | Pollution active agent | *Zero, plus* | *Rate of the process of discharging water with extra amount of substances originated outside the water bodies caused by human activities.* |
| **Water abstraction** | Water abstraction active agent | *Zero, plus* | *Rate of the process of removal or diversion of water from any sources either permanently or temporarily including ground water or surface water.* |

# 4 Model fragments

Figure 6 presents River Mesta case study model fragments hierarchy. Model contains 36 model fragments – static, process and agent, describing the behavior the stream ecosystem.

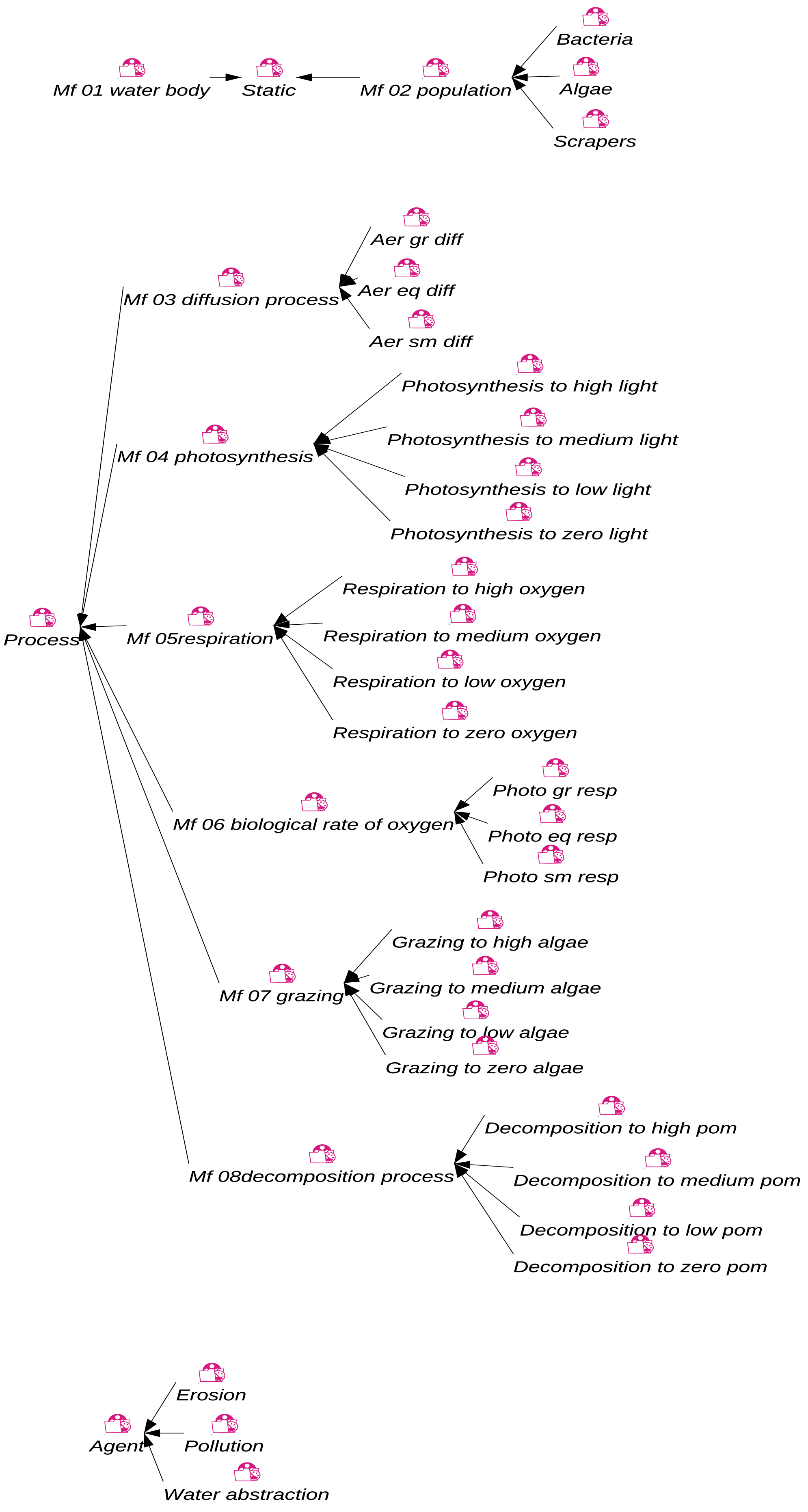



*Figure 6.River Mesta: Model fragments hierarchy*

## *4.1 Static model fragments*

Static model fragment " **Water body**"

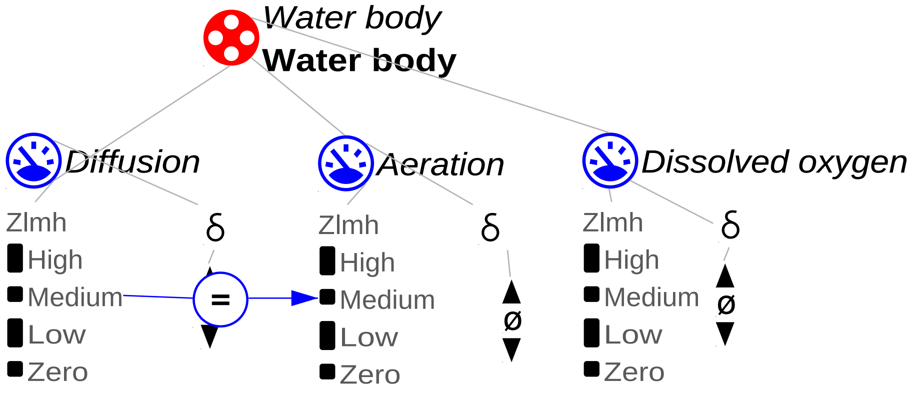



*Figure 7. Model fragment "Water body"*

This model fragment (Fig.7) represents the main features of a water body – Amount of DO, diffusion, aeration.

Diffusion is a collective quantity describing the process of diffusion of the oxygen in water to the atmosphere. This is a physical law on the dependencies of the amount of DO on the water temperature. The water temperature is strongly depended on Radiant energy (intensity of solar radiation). The higher is the temperature (naturally in summer daily conditions) of the river, as intensive is the process of reverse diffusion. The process is always active while any water body contains some amount of heat measured by its temperature.

Aeration is another collective quantity, related to the flow/velocity of a stream. This is a parallel additional process to the diffusion of oxygen from the air facilitated by the downstream turbulent movement of water masses. This turbulence mixes air and water and thus increases the amount of DO. In normal condition, this process is always active as far as the streams and rivers run and thus are capable to mix water and air.

Static model fragment **"Population**"

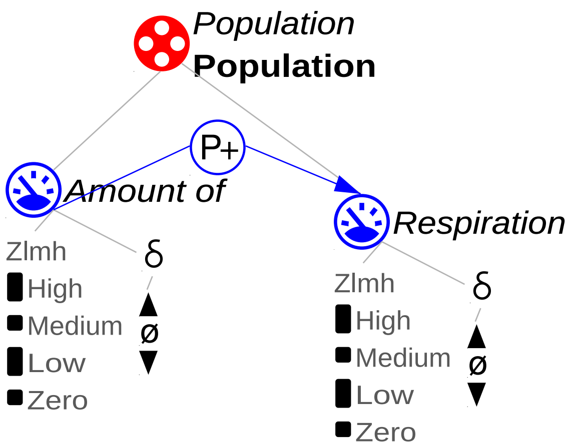



*Figure 8. Model fragment "Population"*

This model fragments (Fig.8) describe the main characteristics of one population - Amount of and some Respiration rate. All aquatic organisms, including producers, consume DO for their respiration thus decreasing its amount in water.

If the amount of population increases, the Respiration also increases, therefore there is P+ relation between them.

This model fragment has three additional model fragments, describing the specific characteristics of populations of algae, bacteria and scrapers (producers, consumers and reducers). Populations of algae have specific quantity **Photosynthesis (Fig. 9)**, Populations of Scrapers – **Grazing (Fig. 10)**, the process of feeding, and bacterial populations decompose organic matter, and reduce pollution, so bacterial population have additional quantity – **Bacterial degradation (Fig. 11)**.

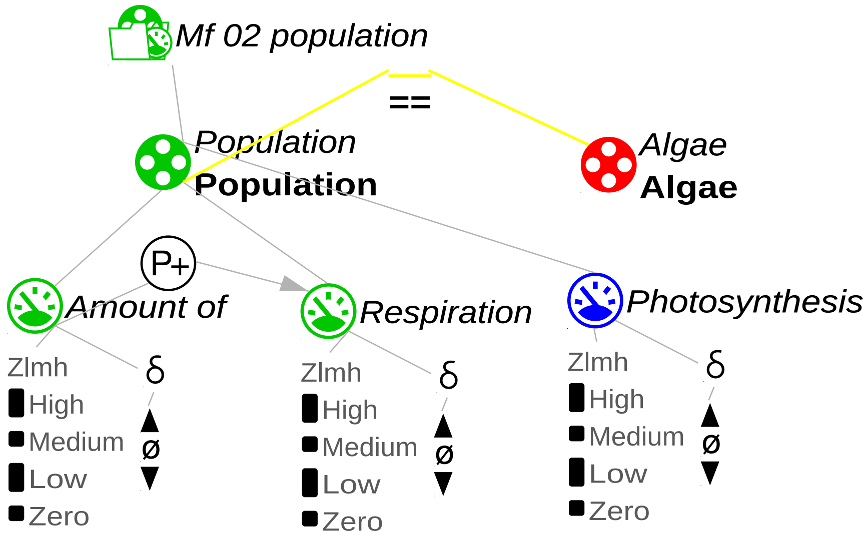



*Figure 9. Model fragment "Algae"*

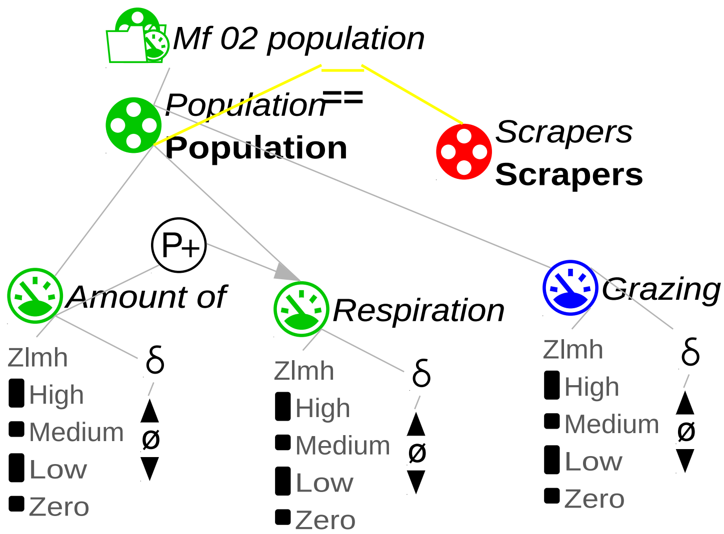



*Figure 10. Model fragment "Scrapers"*

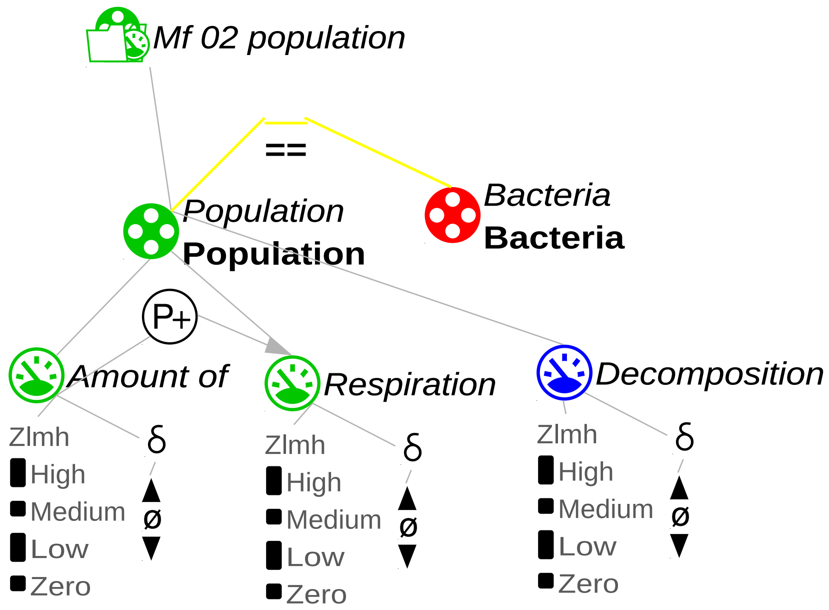



*Figure 11. Model fragment "Bacteria"*

## 4.2 Process model fragments

We use process model fragments to describe processes which take place within the system.

Process model fragment **"Diffusion process"**

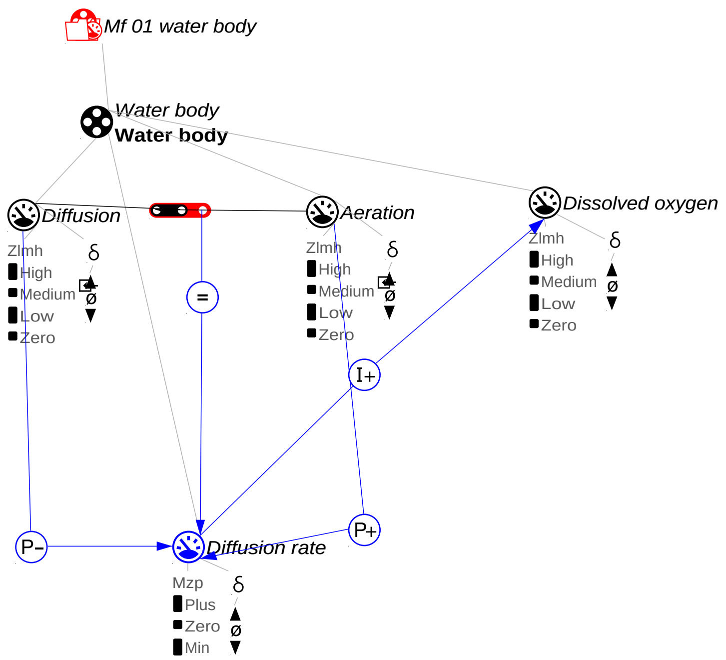



*Figure 12. Process fragment " Diffusion process"*

When the structure is described, we introduce the process of Diffusion rate. This quantity is calculated between Aeration and Diffusion ( Fig.12).

If the Aeration increases, the Diffusion rate also increases, therefore there is P+ relation. If the Diffusion increase, the Diffusion rate decreases, so there is P- relation.

The Diffusion rate determines the changes in the amount of DO; there is I+ relation between them.

The inequalities between Aeration and Diffusion determine the values of Diffusion rate, so we introduce 3 additional model fragments.

When Aeration is equal to Diffusion, then the Diffusion rate is equal to zero ( Fig 13).

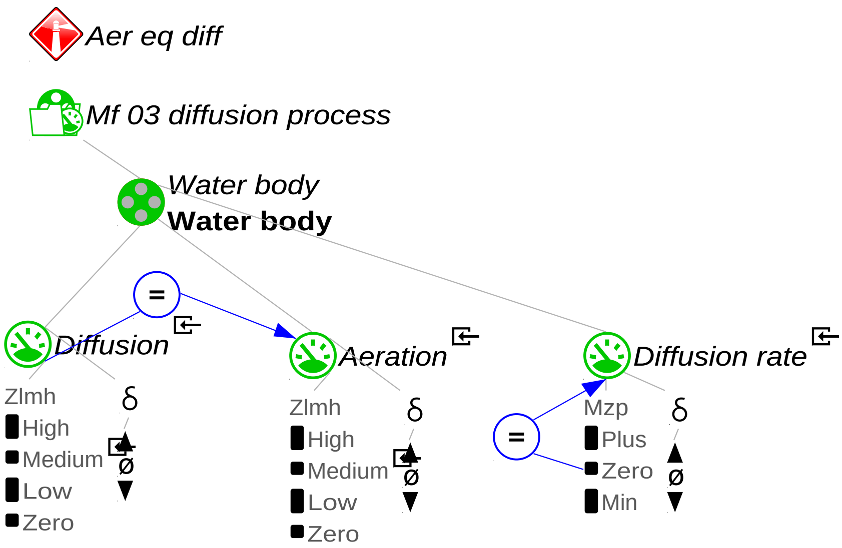



*Figure 13. Model fragment "Aeration equal diffusion"*

When Aeration is greater than Diffusion, then Diffusion rate is greater than zero (Fig 14). These conditions are typical mainly during the night when there is no solar radiation and in winter when the solar radiation is not so intensive, and amount of accumulated in the water light diminishes.

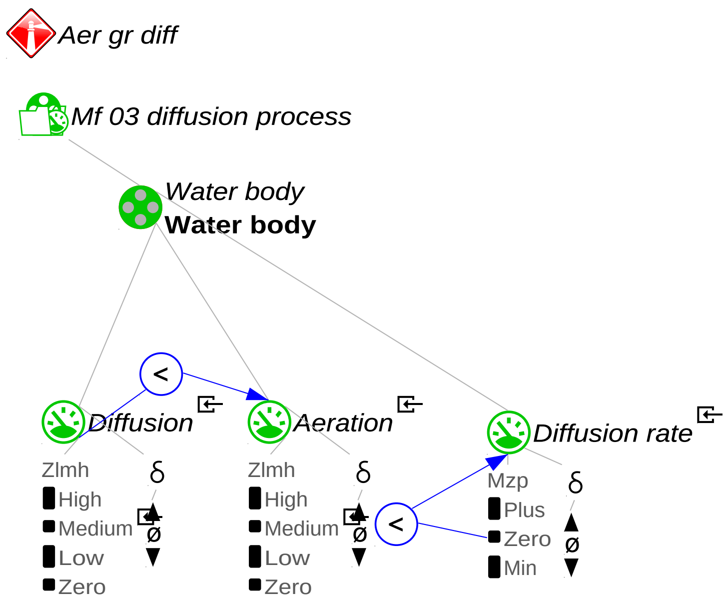



*Figure 14. Model fragment "Aeration greater diffusion"*

When Aeration is smaller than Diffusion, the Diffusion rate is smaller than zero (Fig 15). This phenomenon is typical in summer daily conditions in some extend river stretch with low flow velocity. High temperatures increases the amount of heat accumulated in water body, which intensify the process of Diffusion.

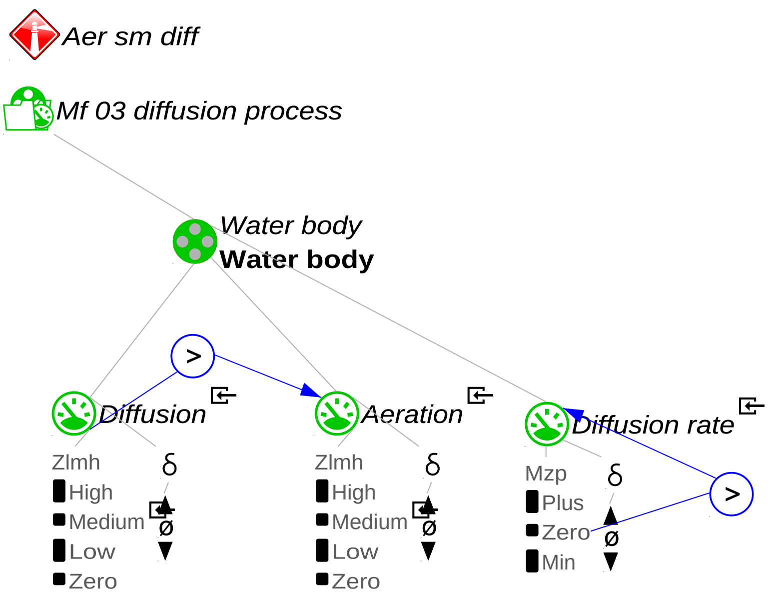



*Figure 15. Model fragment "Aeration smaller diffusion"*

Process model fragment **"Photosynthesis"**

In all aquatic environments, light from solar radiation is the primary factor for oxygen production through the process of photosynthesis. All plants, including aquatic algae and macrophytes, are capable to photosynthesize utilizing the light in the range of wavelengths between 400 and 700 nm (visible light). The final result of the process is production both of organic matter of their bodies and of free oxygen which is dissolving in water. Light intensity is crucial for the rate of photosynthesis and thus for the amount of the oxygen produced by the algae. Effects of pollution and erosion due to effluents of organic and/or inorganic particles in water can also seriously affect the rate of photosynthesis reducing the light penetration.

If the amount of suspended solids increases (fig 16), the light available in water decreases, there is P- relation. If the Light available in water increases, the Photosynthesis also increases so there is P+ relation. If the Amount of algae increases the Photosynthesis also increases – P+.

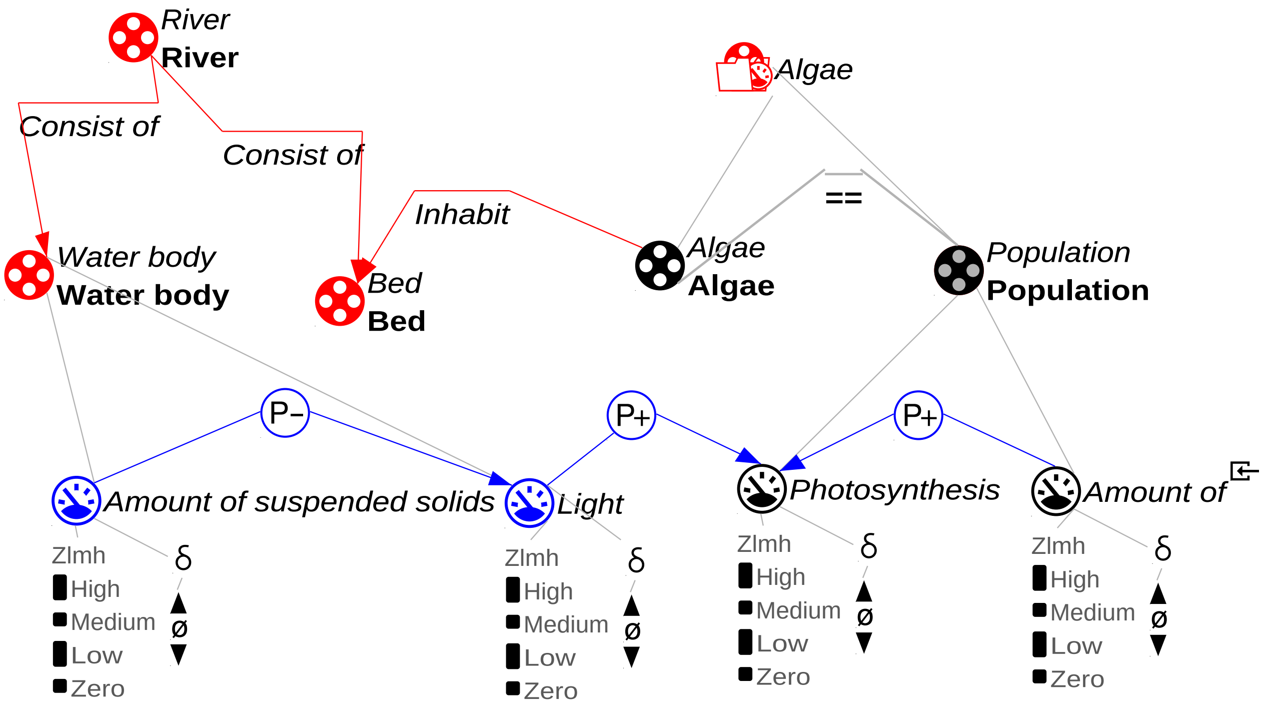



*Figure 16. Model fragment "Photosynthesis"*

There are two parameters that determine the value of the Photosynthesis – Amount of algae and Light available in water therefore we introduce 4 additional model fragments to describe these conditions – by using correspondence.

When Light available in water is zero, the Amount of Algae could be zero, low, medium or high but photosynthesis is zero (fig 17). We can observe such a phenomenon during the nights, when the available light is zero (there is no radiant energy).

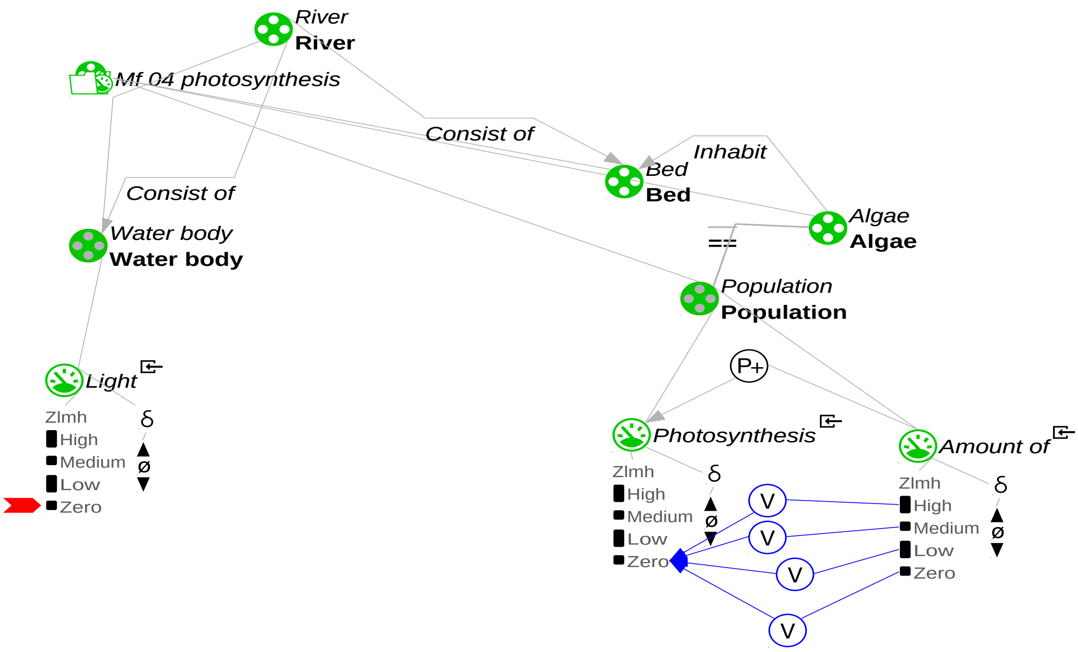



*Figure 17. Model fragment "Photosynthesis to zero light"*

When the light is low, the Amount of algae could be zero, low, medium, high but Photosynthesis could be only zero or low ( Fig 18).

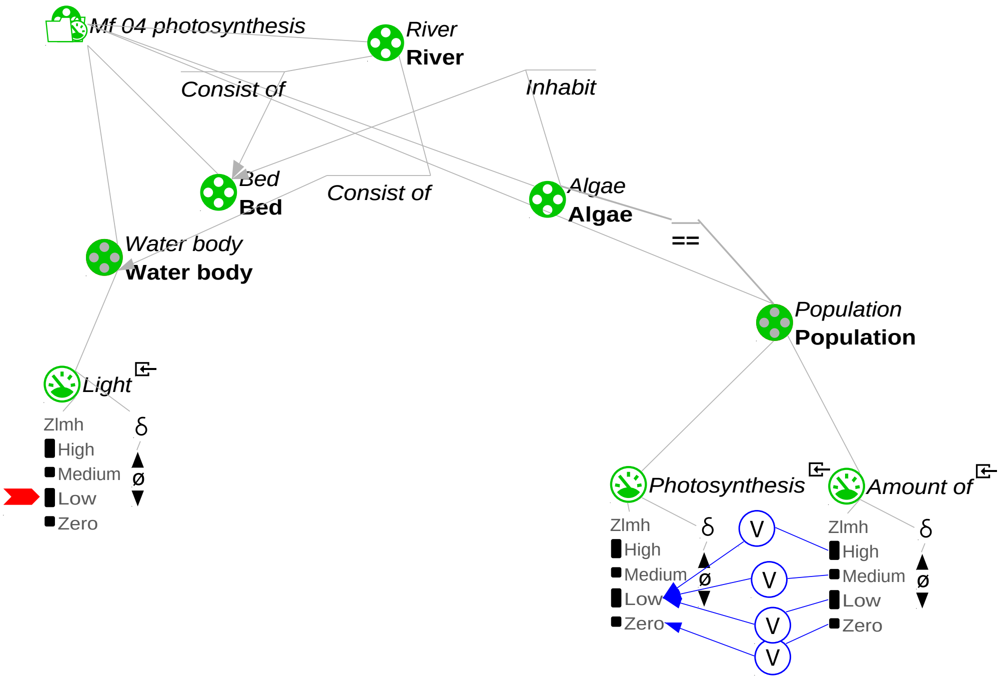



*Figure 18. Model fragment "Photosynthesis to low light"*

When light is medium (Fig 19). Actually this is normal conditions for the process of photosynthesis.

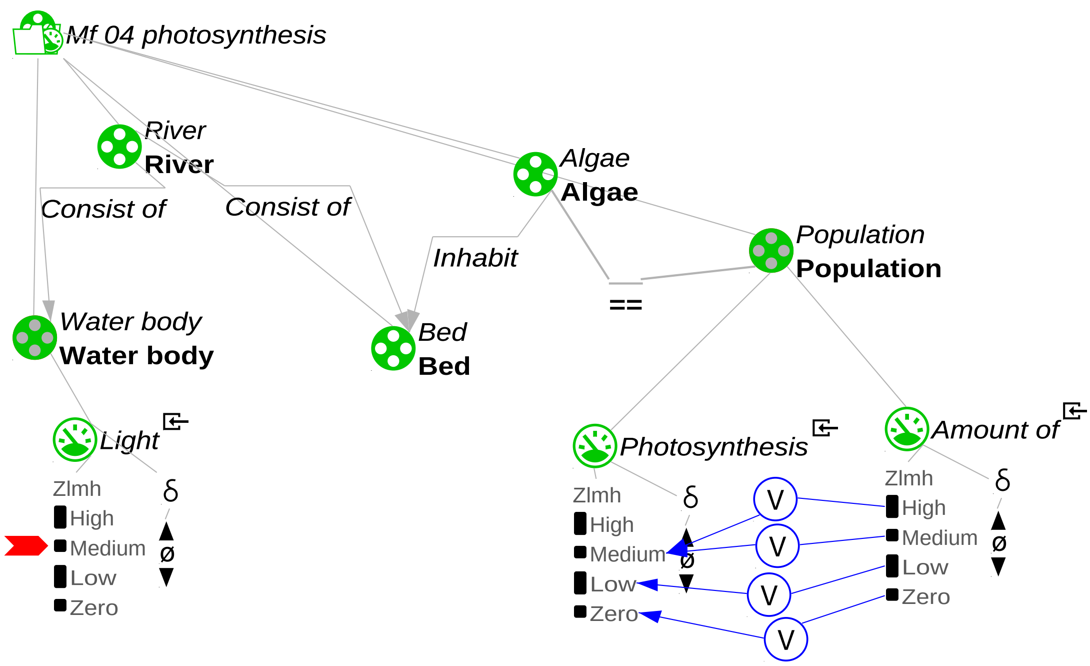



*Figure 19. Model fragment " Photosynthesis to* medium light"

When Light available in water is high there is a full correspondence between Amount of algae and Photosynthesis (Fig 20).

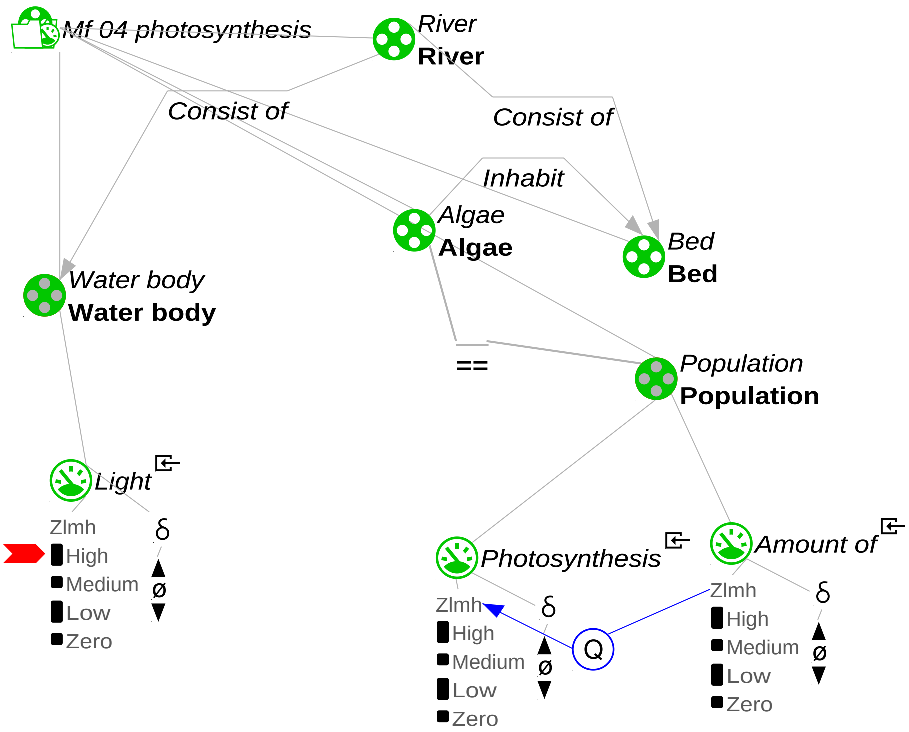



*Figure 20. Model fragment "Photosynthesis to high light"*

Process model fragment **"Respiration"**

Respiration is a process of oxygen consumption when organisms utilize the energy from their food. All aquatic organisms, including producers, consume DO for their respiration thus decreasing its amount in water. The process is always active in natural water bodies. Two are the main factors needed for the process of Respiration – Amount of population and DO (Fig 21).

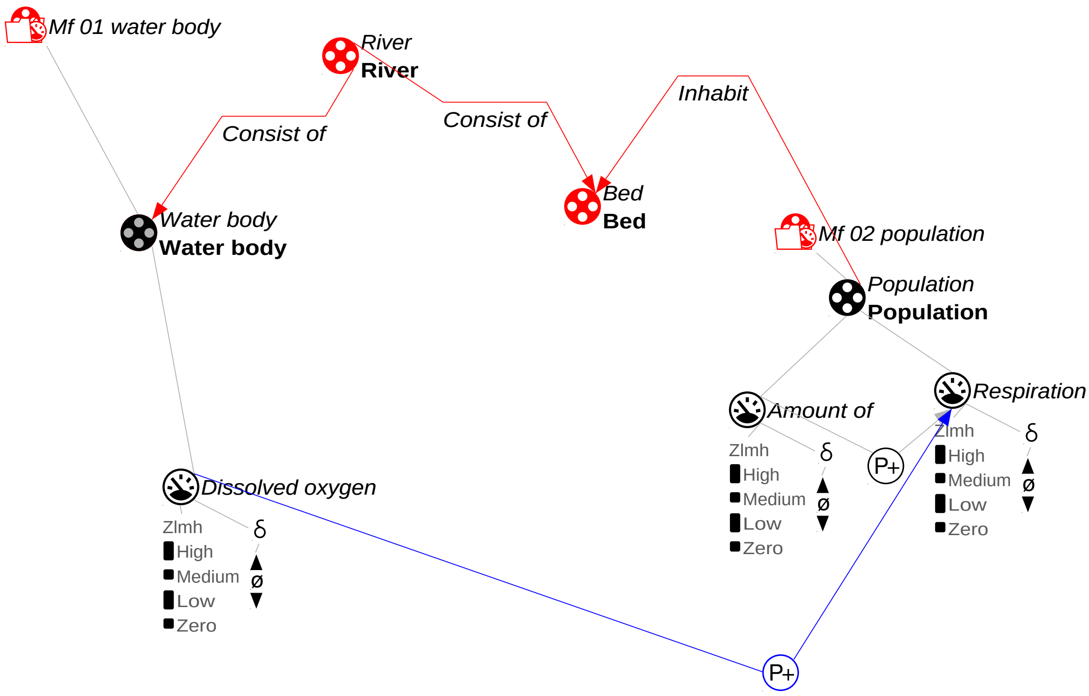



*Figure 21. Model fragment "Respiration"*

When the DO is zero (fig 22). There is no chance for surviving of organisms without oxygen. Only some bacterial population can resist without oxygen (anaerobic organisms).

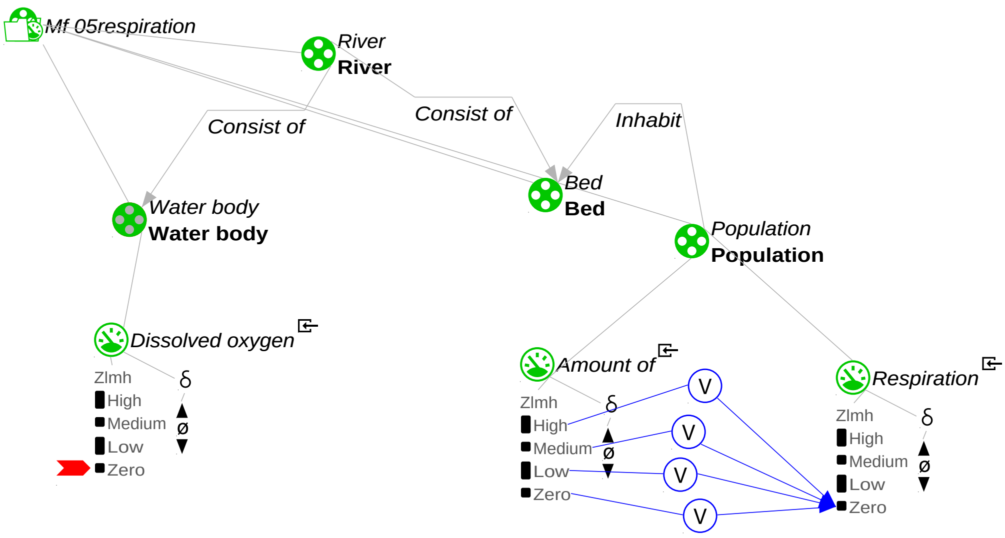



*Figure 22. Model fragment "Respiration to zero oxygen"*

When DO is low (Fig 23). Actually in natural water bodies, conditions with total lack of oxygen are rarely observed. In strongly polluted streams, the amount of DO can decrease. Only some populations are adapted to live in conditions with very low oxygen amounts (microaerobic conditions).

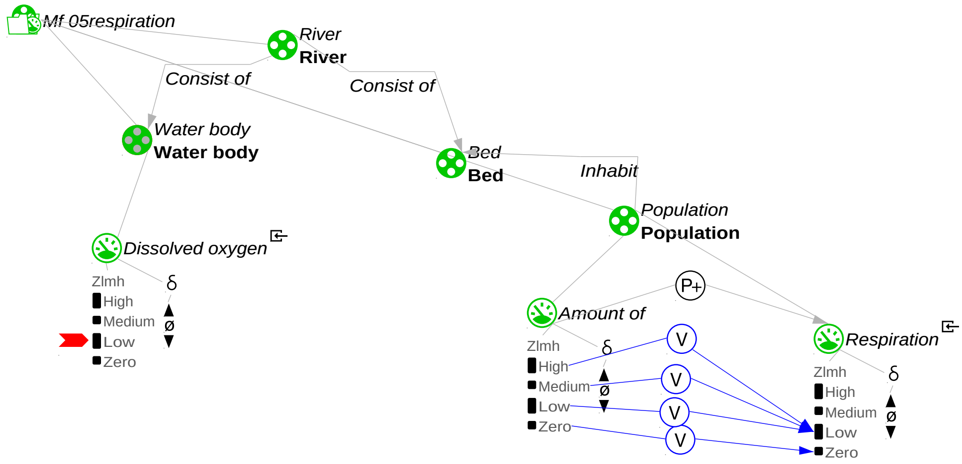



*Figure 23. Model fragment "Respiration to low oxygen"*

The other two model fragments are typical for stream ecosystems, where we can observe variations of the amount of DO due to various influences –aeration, diffusion, respiration, photosynthesis, erosion etc.

When DO is medium ( Fig 24).

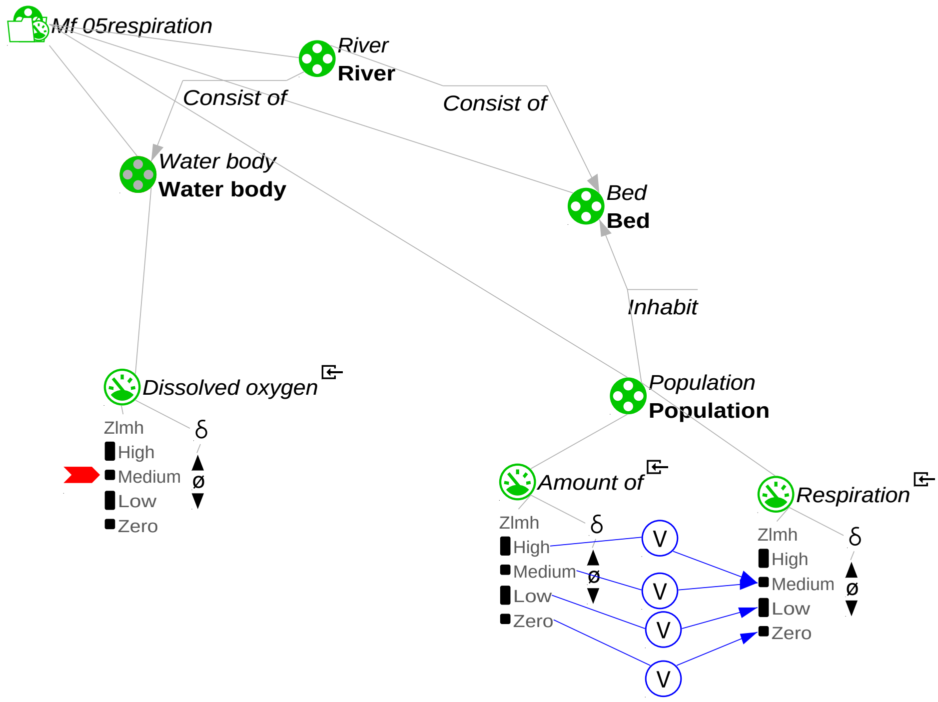



*Figure 24. Model fragment "Respiration to medium oxygen"*

When DO is high ( Fig 25).

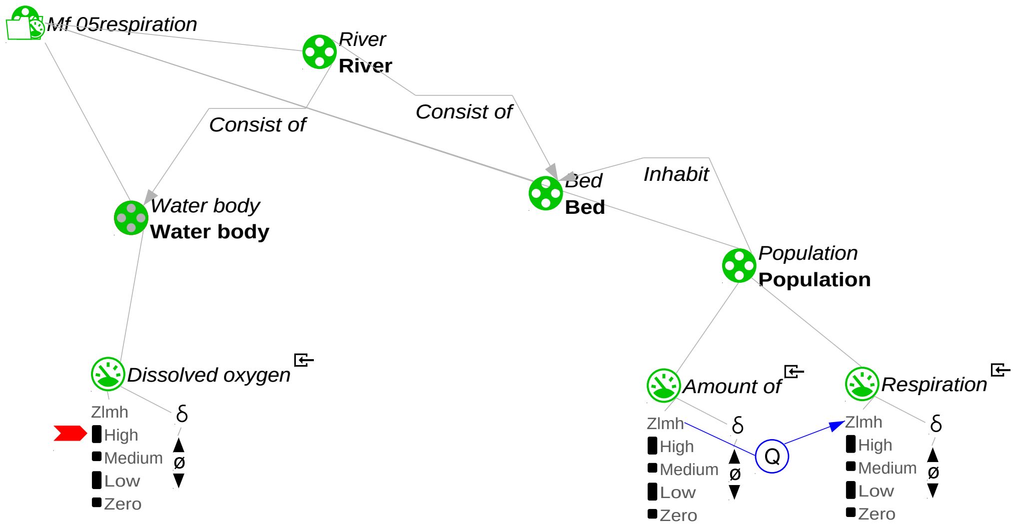



*Figure 25. Model fragment "Respiration to high oxygen"*

Process model fragment **"Biological oxygen flux"**

Photosynthesis and Respiration are two opposite processes, which determine the Biological oxygen flux in a Water body. Photosynthesis minus Respiration is equal to Biological oxygen flux (Fig. 26). When Respiration increases, the Biological oxygen flux decreases, so there is P- relation. If the Photosynthesis increases, the Biological oxygen flux also increases, so there is P+ relation. Biological oxygen flux is another quantity which specifies the behaviour of DO, there is I+ relation.

The inequalities between Respiration and Photosynthesis, determines the values of Biological oxygen flux, so we introduce three additional model fragments to describe this by using correspondences.

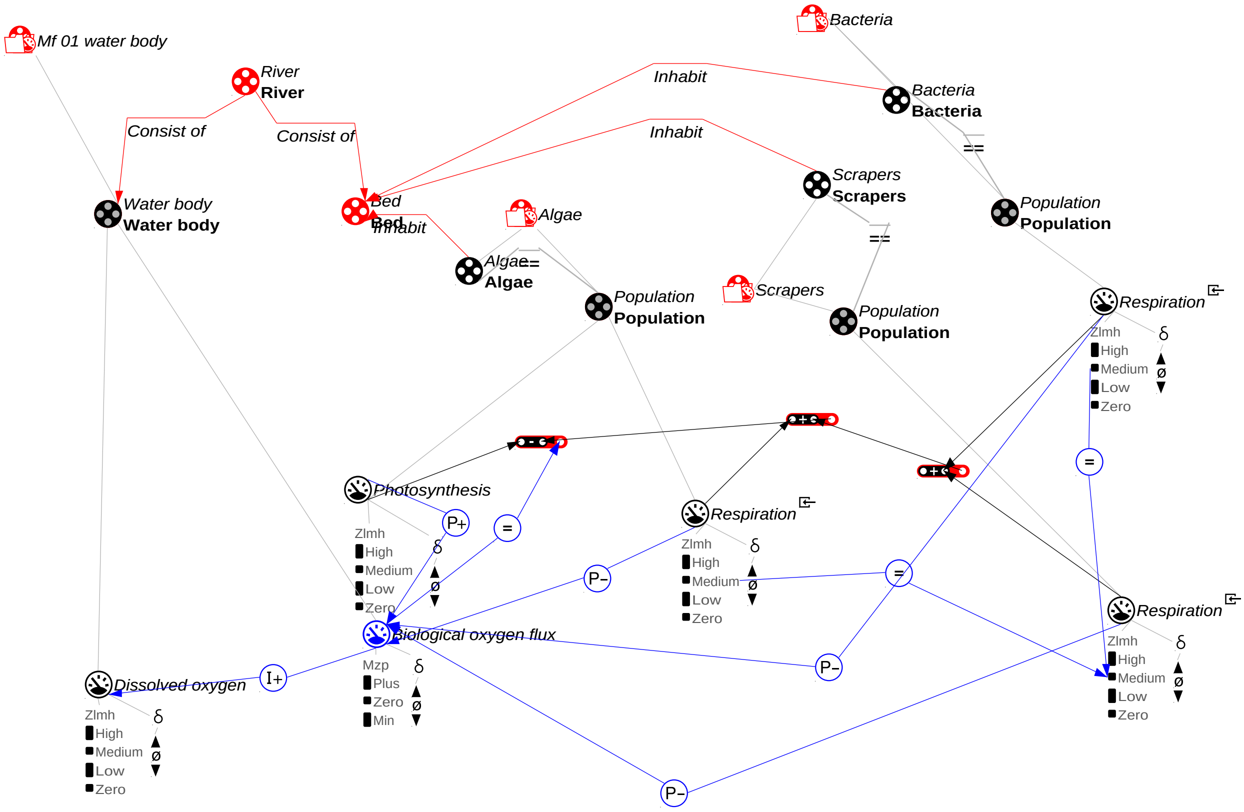



Figure 26. Model fragment "Biological oxygen flux"

When Photosynthesis is equal to Respiration (Fig 27).

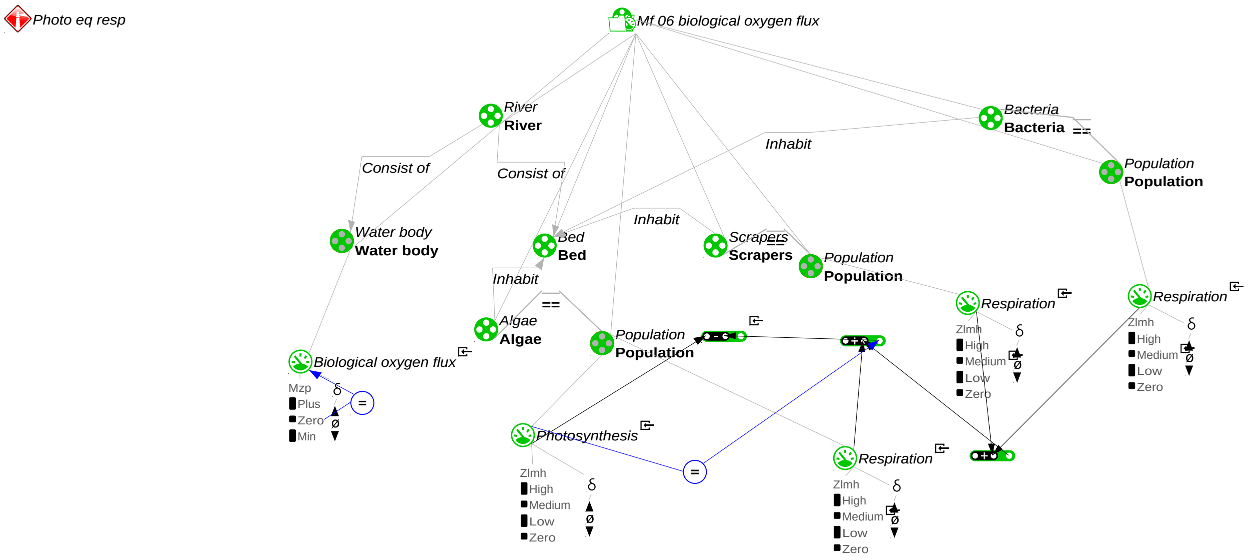



Figure 27. Model fragment “Photo eq resp”

When Photosynthesis is greater than Respiration (Fig.28). We can see this during the days.

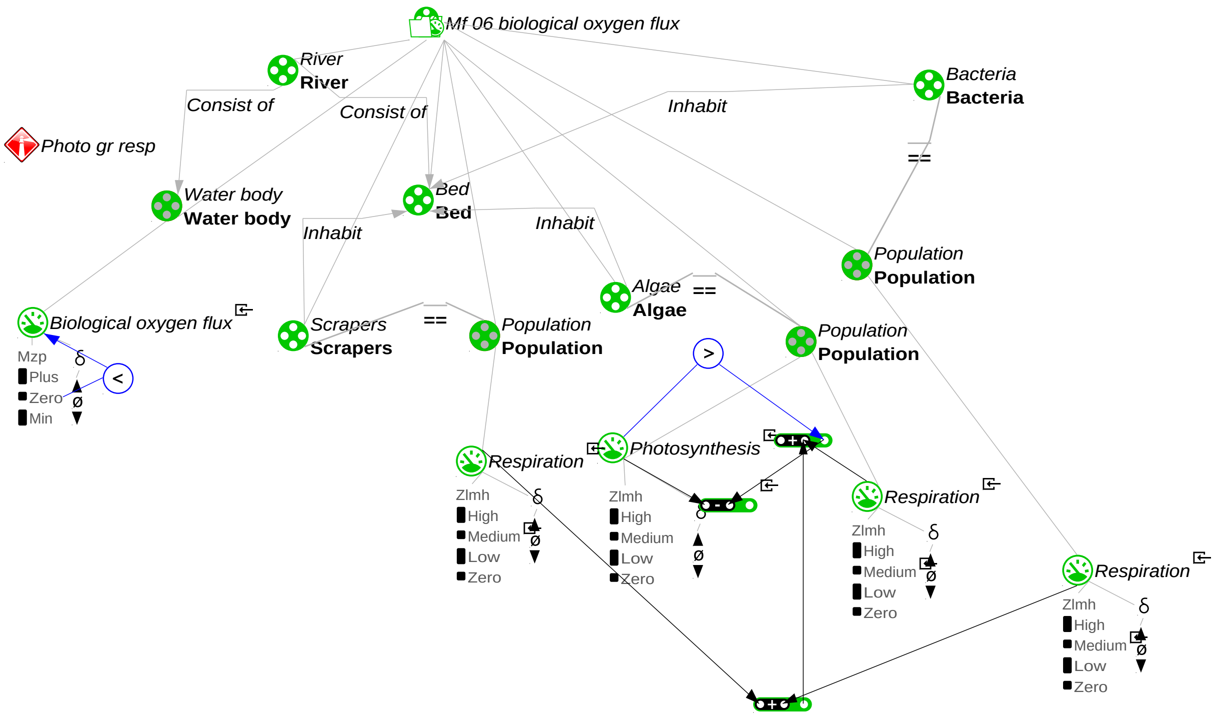



Figure 28. Model fragment “Photo gr resp”

When Photosynthesis is smaller than respiration (Fig 29) . We can observe this during the nights – conditions without light.

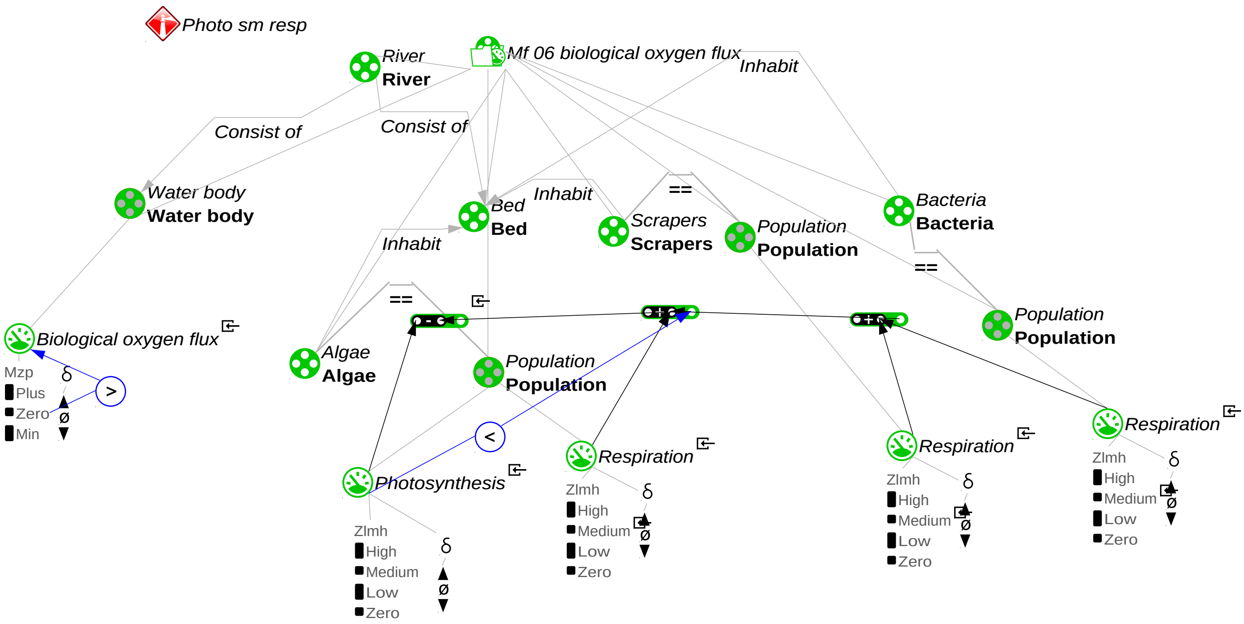



Figure 29. Model fragment “Photo sm resp”

Process model fragment **"Grazing"**

Scrapers/grazers are one of the functional feeding groups of large number of invertebrates which feed on while they scrape/graze the thin layer of algae on the bottom substrata. The process of Grazing determines some rate of the process of consumption (P +). If there is some Consumption rate the amount of algae will decrease (I- relation) (Fig. 30).

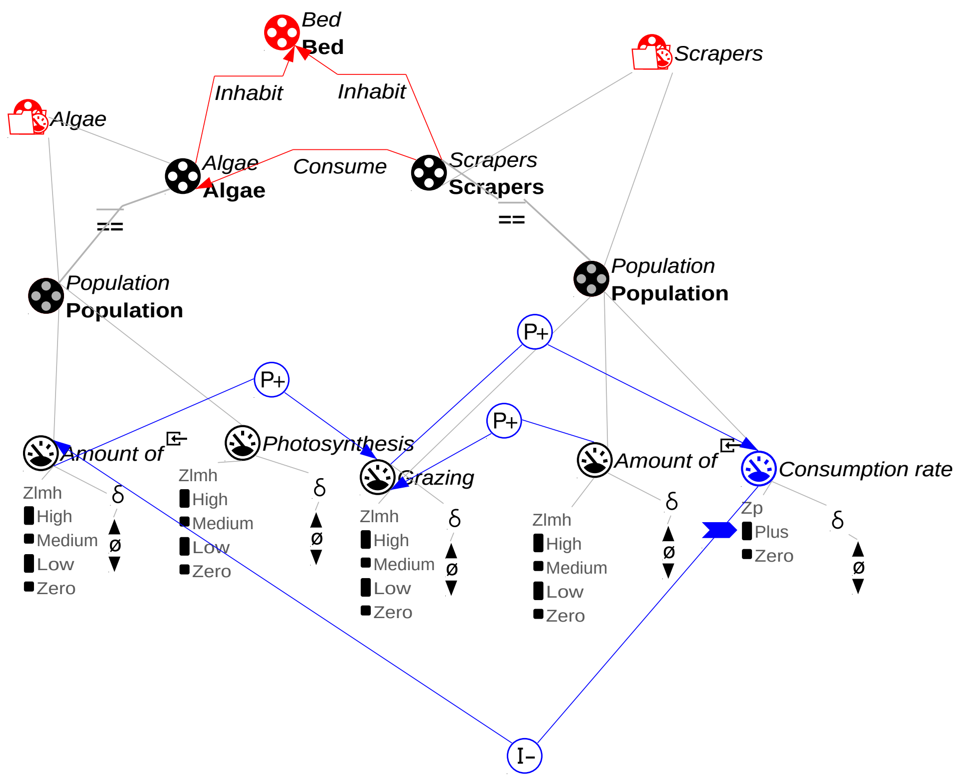



*Figure 30. Model fragment "Grazing"*

The Grazing depends mainly on the amount and availability of food -Amount of algae, so we introduce 4 additional model fragments to show these details.

When the Amount of algae is zero. No food, no grazing, no chance for populations of scrapers to survive (Fig 31).

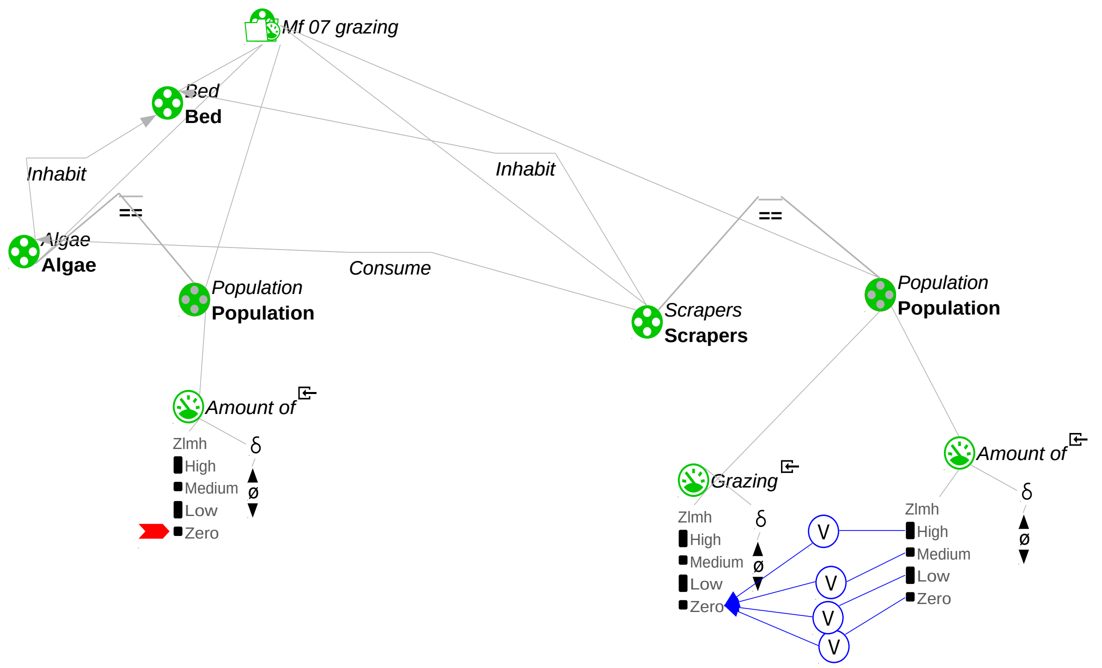



*Figure 31. Model fragment "Grazing to zero algae"*

When the Amount of algae is low (Fig 32).

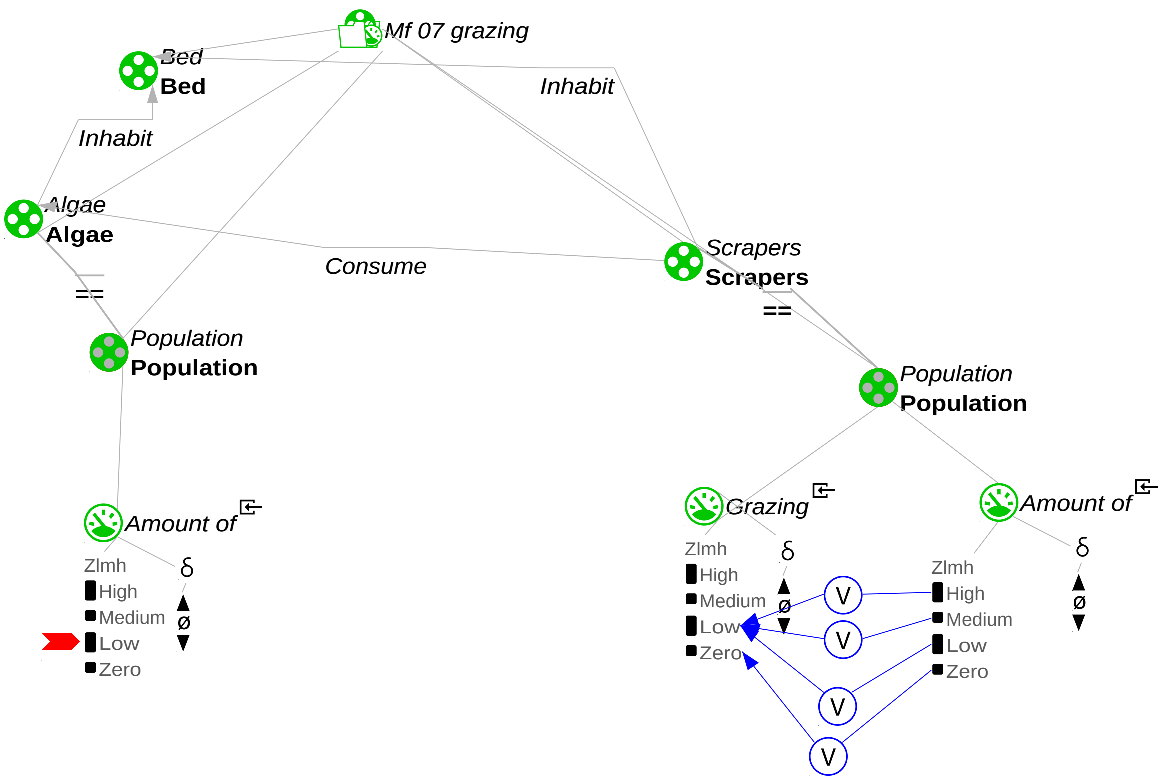



*Figure 32.Model fragment "Grazing to low algae"*

When Amount of algae is medium (Fig 33).

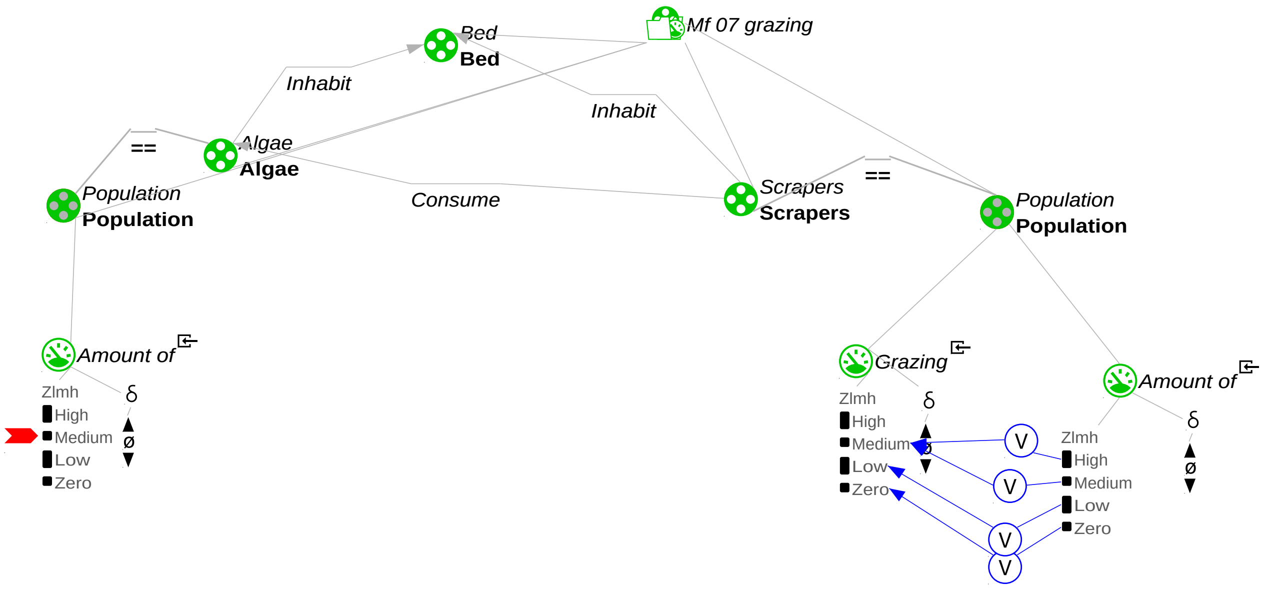



*Figure 33. Model fragment " Grazing to medium algae"*

When the Amount of algae is high (Fig 34).

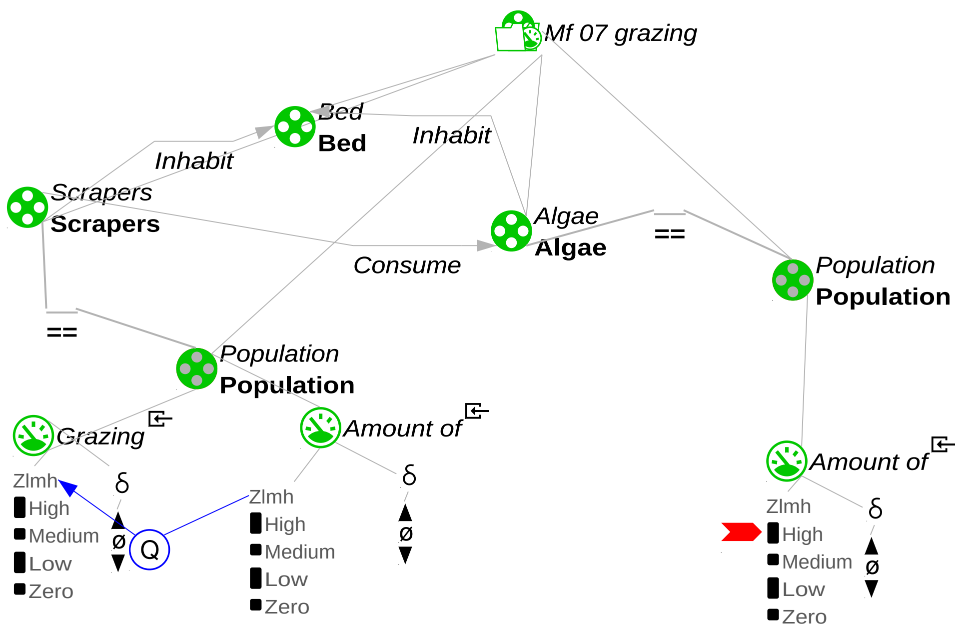



*Figure 34. Model fragment "Grazing to high algae"*

Process model fragment "**Decomposition process"**

Decomposition is a process of consequent degradation of organic matter originated from dead bodies of aquatic organisms and inputs from watershed (leaf litter, any residuals from living activities and dead bodies of terrestrial organisms). Organic load is gradually eliminated by the activities of bacteria. This process requires sufficient concentrations of oxygen, and involves the breakdown of complex organic molecules into simple inorganic molecules. Attached micro organisms in streams play a greater role in self-purification process.

The process is driven by reducers (bacteria) which utilize organic matter by means of biochemical processes of degradation. The process of decomposition specifies some Decomposition rate (P+) (Fig. 35). If there is some Decomposition rate, the amount of Particulate organic matter is going to decrease, so there is I- relation.

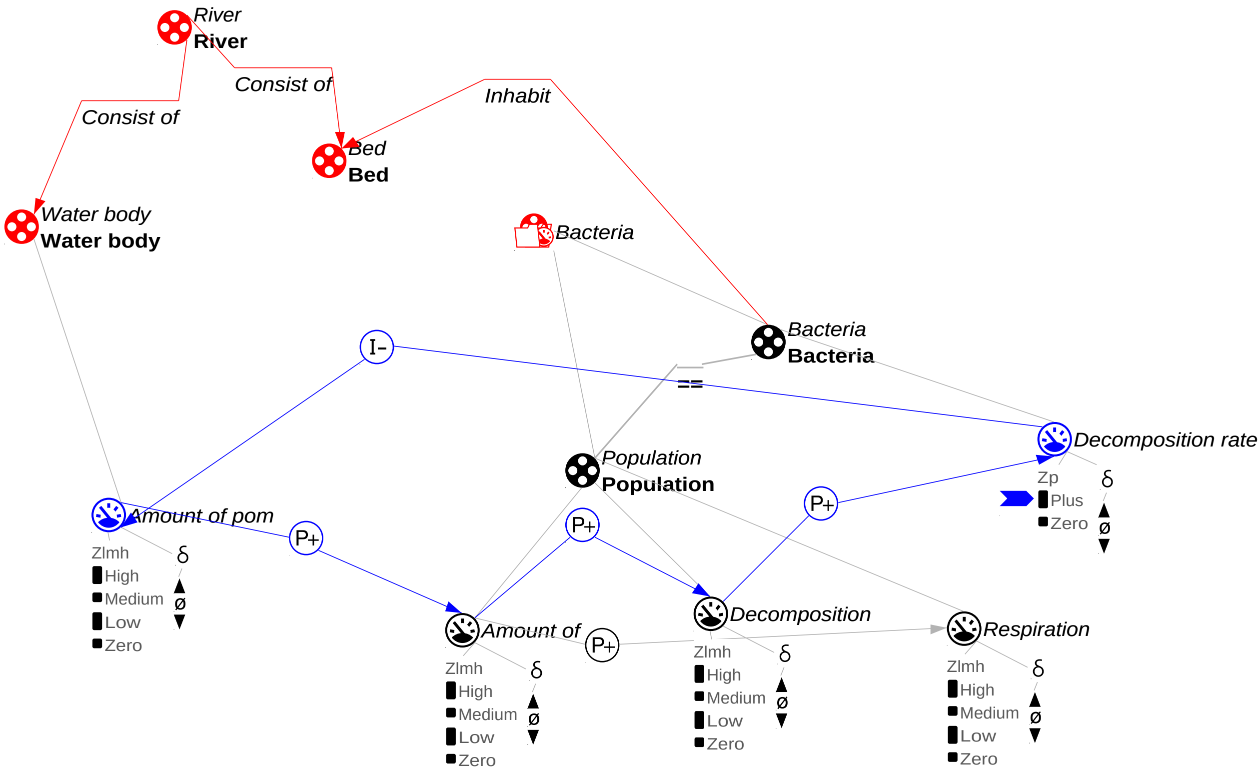



*Figure 35. Model fragment "Decomposition process"*

This process depends mainly on both Amount of POM and Amount of bacteria, so we introduce 4 additional model fragments to show this details.

When the Amount of POM (Particulate organic matter) is zero ( Fig 36), there is no available food for bacteria, so the Process of Decomposition is zero.

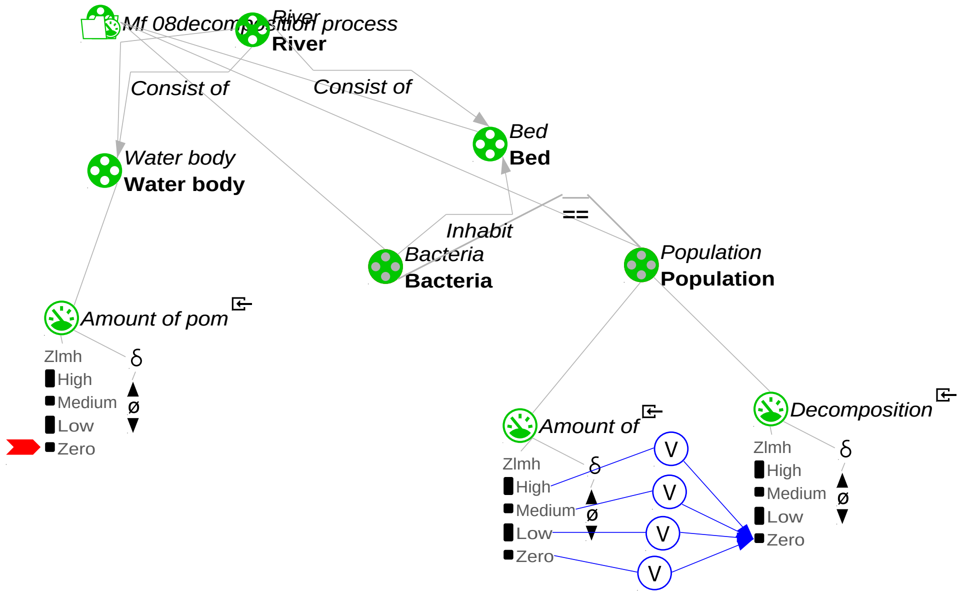



*Figure 36 Model fragment "Decomposition to zero POM"*

When the Amount of POM is low ( Fig 37).

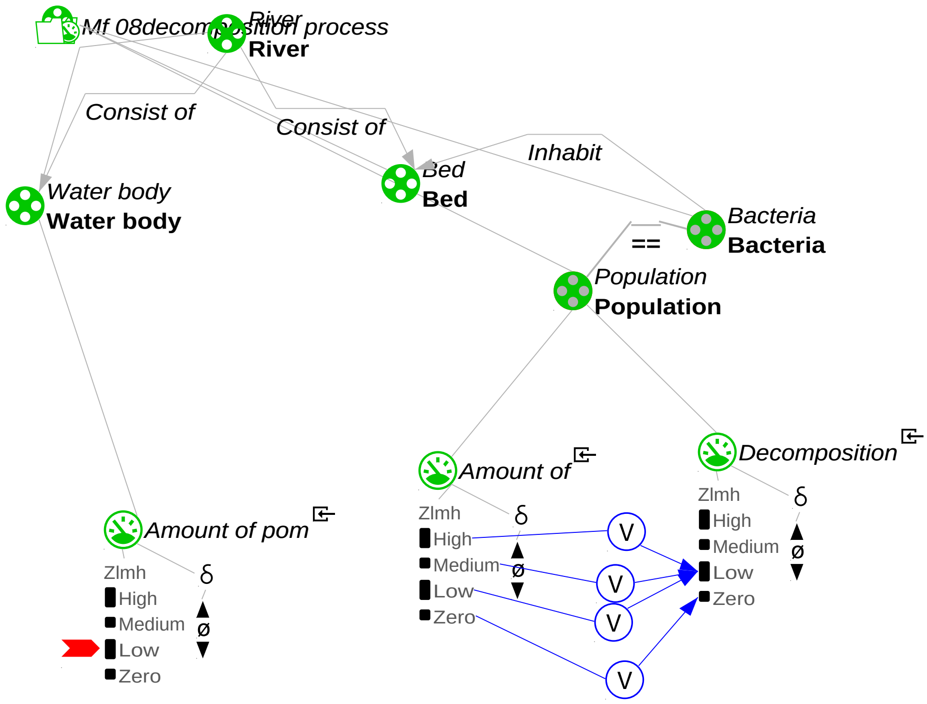



*Figure 37 Model fragment "Decomposition to low POM"*

When the Amount of POM is medium (Fig 38)

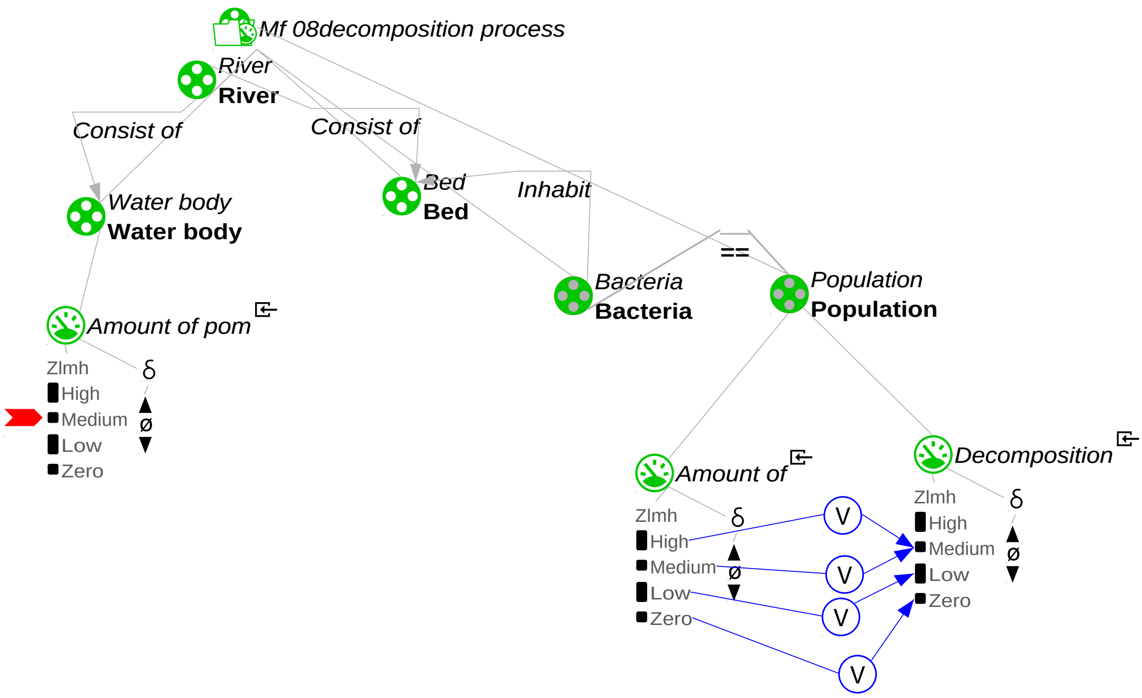



*Figure 38 Model fragment "Decomposition to medium POM*

When the Amount of POM is high (Fig 39).

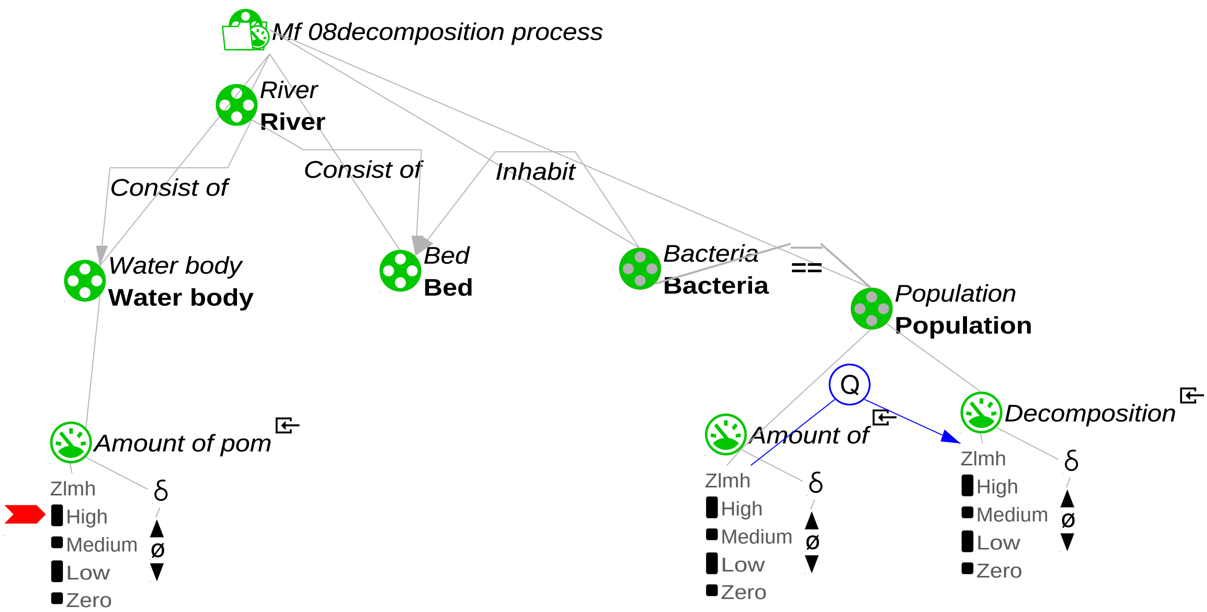



*Figure 39 Model fragment "Decomposition to high POM"*

### *4.3 Agent model fragment*

Agent model fragment **"Erosion"**

Erosion is a process of removal of upper soil horizons by precipitation and wind resulting in reduction of soil fertility and loss of essential nutrients for terrestrial plants. Removed particles enter the water body as suspended solids thus they increase the turbidity and thus decrease the light conditions necessary for oxygen production by algae. The higher is the amount of suspended solids, the less is the rate of photosynthesis and amount of oxygen produced is lower ( Fig 40).

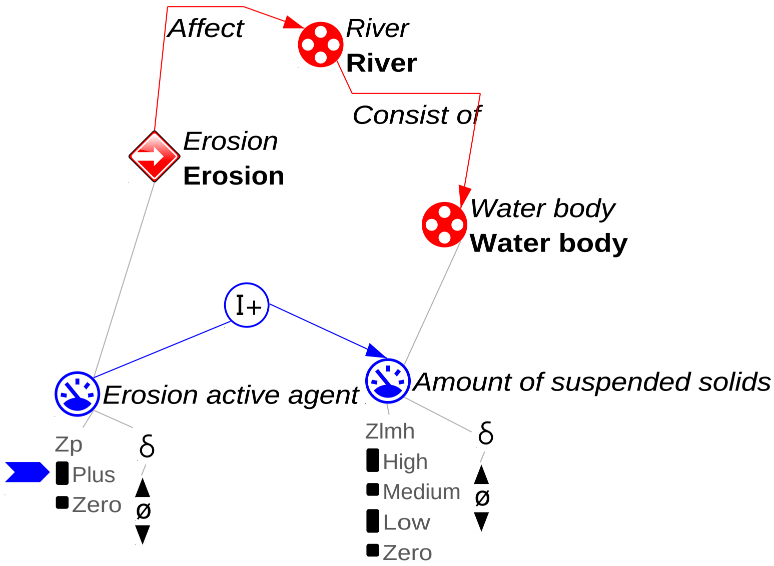



*Figure 40. Model fragment "Erosion"*

Agent model fragment "**Pollution**"

Pollution is a process of discharging water with extra amount of substances originated outside the water bodies, mostly from households, industries and other human activities in watershed. These extra amounts of substances may change significantly the ecological status of a water body and thus the ecosystem health deteriorating the structure and functioning of both physical and biological processes in aquatic ecosystems. In contrast to other water contaminants both inorganic (nutrients, heavy metals) or organic (oil products, pesticides, great number of various chemical products/chemicals) in their nature, external loads with particulate organic matter (POM) affect directly the oxygen balance accelerating the oxygen consumption by reducers until full exhaustion of the DO. The result is substantial shift, even destruction of other biotic components (producers, consumers) of aquatic ecosystems and loss of many of ecosystem services humans can use from water bodies such as water quality (clean water for different purposes) and safe biological resources (fish). The effects of pollution depend on the amount of wastewater discharge and water temperatures responsible for rate of physical and biological processes relevant to the oxygen balance of a water body.

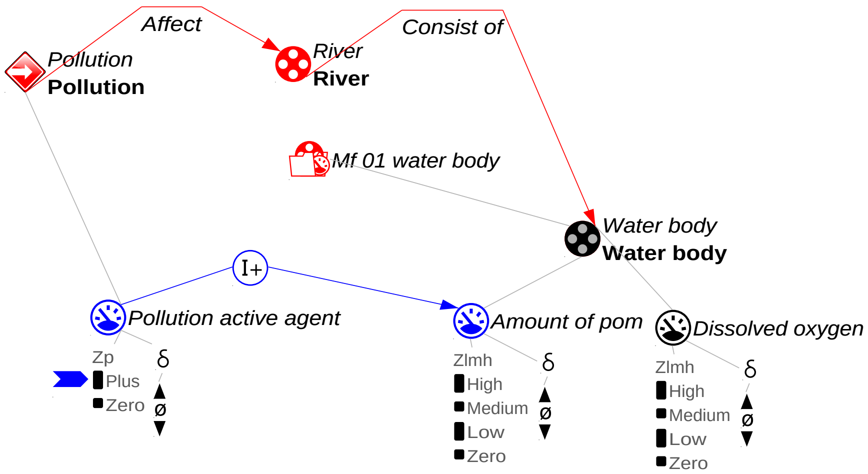



*Figure 41 Model fragment "Pollution"*

Agent model fragment **"Water abstraction"**

Humans need water for various purposes of their every-day life (drinking, washing, bathing) and many economic activities – agriculture (irrigation), industry (supply for technological processes and manufactured goods), etc. The common practice to meet these needs is water abstraction from water bodies and re-direction of some water amounts through water supply systems for further use by humans. Decreasing water discharge in natural water bodies affects significantly all physical and biological processes which are responsible for setting up the oxygen balance and thus may affect negatively the ecological status and ecosystem health of water bodies downstream the abstraction point.

The process is active in case of water abstraction for human needs. The effects of water abstraction depend on the amount of water abstracted. The greater is the abstracted amount, the less is the residual water in affected water body and consequent effects on ecological state and ecosystem health relevant to the physical and biological processes responsible for DO balance in a water body. Water abstraction influences aeration. Aeration is collective quantity, describing flow/velocity of a stream. The decreasing of residual water in stream, decrease flow/velocity of river, thus diminishes the capacity of water to mix the air – which is presented by aeration.

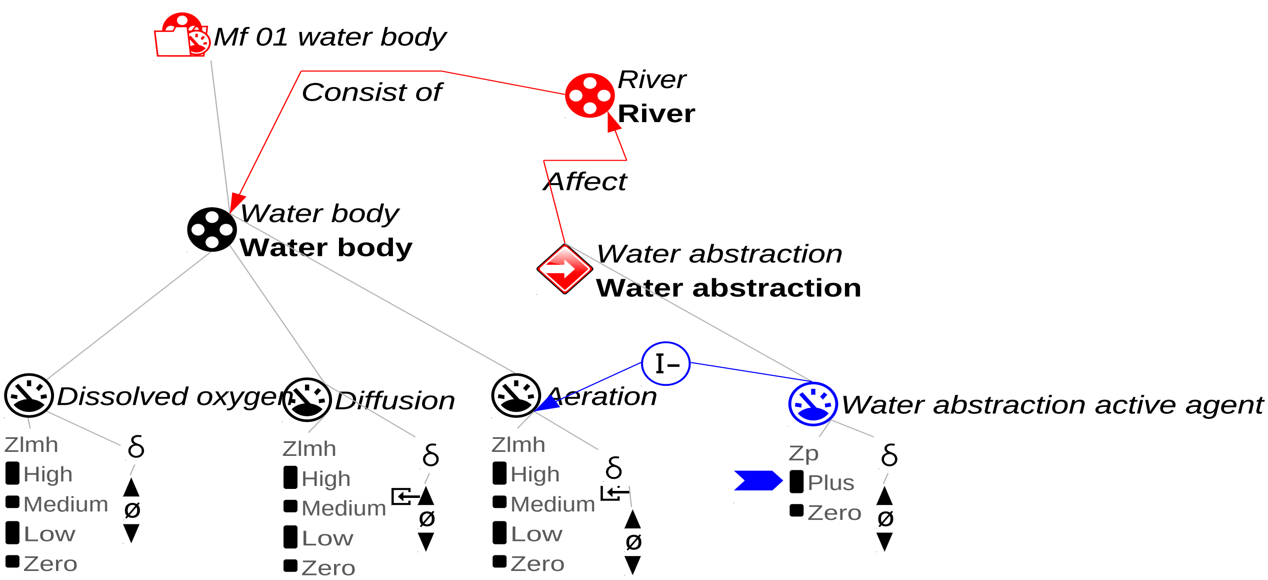



*Figure 42 Model fragment "Water abstraction"*

# 5 Scenarios and Simulations

River Mesta case study model presents three type of scenarios and related simulations. These scenarios are related with behavior of DO under different environmental and anthropogenic conditions.

## *5.1 First type of scenarios describe physical part of the system*

### 5.1.1 Sc01 Physical part of the system oxygen saturation.

This simple scenario is constructed only with tree quantities. The main goal is to present the equilibrium of DO (the process of oxygen saturation), when the processes of aeration and diffusion are equal.

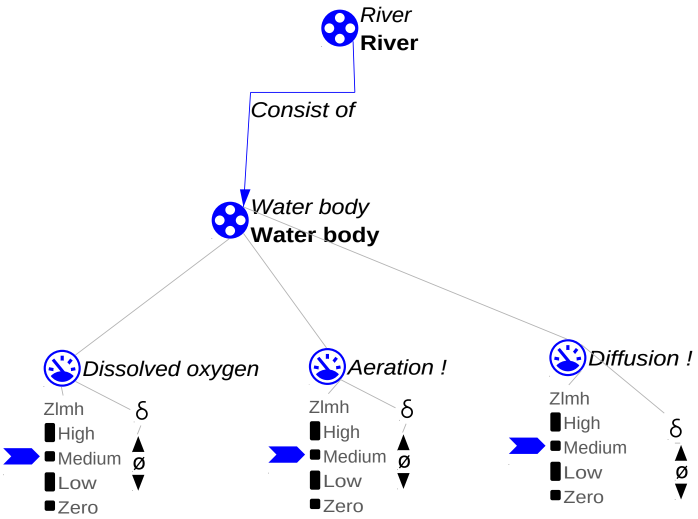



*Figure 43 Scenario 01 "Physical part of the system – oxygen saturation"*

When the two processes are equal the amount of DO in river water doesn't change – stable conditions (Figure 49, Figure 49a).

| | |
|---|---|
| Scenario name | Physical part of the system- oxygen saturation |
| Full simulation | 1 state |
| Initial states | 1 |
| End states | There is no end state |
| Relevant behavior path | No path |
| Behavior description | When the two processes Aeration and Diffusion are *medium* and *stable* (two processes are equal), the Amount of DO doesn't change – *medium* and *stable*. This quantity shows stable conditions. |

Table 3: Simulation summary: Scenario 01 Physical part of the system – oxygen saturation.

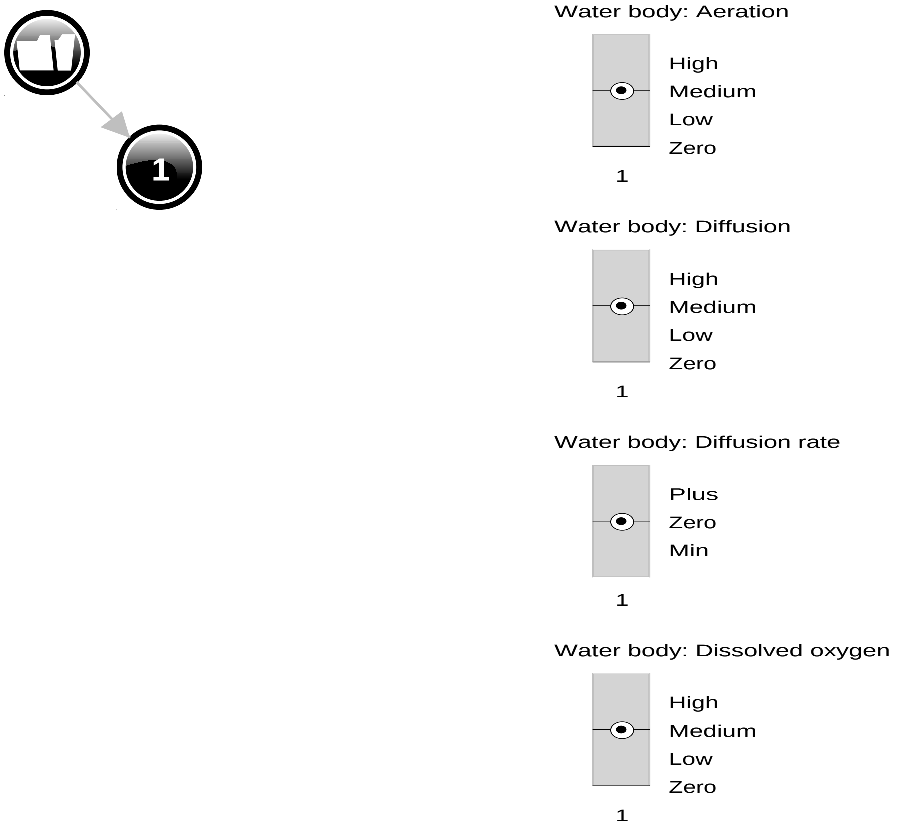



*Figure 44:. Scenario 01 “Physical part of the system – oxygen saturation”- Simulation and Value history*

### 5.1.2 Sc 01a Aeration greater than diffusion

The scenario is constructed of three quantities. The difference is in fact that the process of Aeration is greater than the Diffusion – values *high* and *stable*. Naturally in mountain streams, the process of aeration is greater than the process of reverse diffusion (diffusion of oxygen molecules into the atmosphere), because of the fast downstream movement of water driven by gravitation.

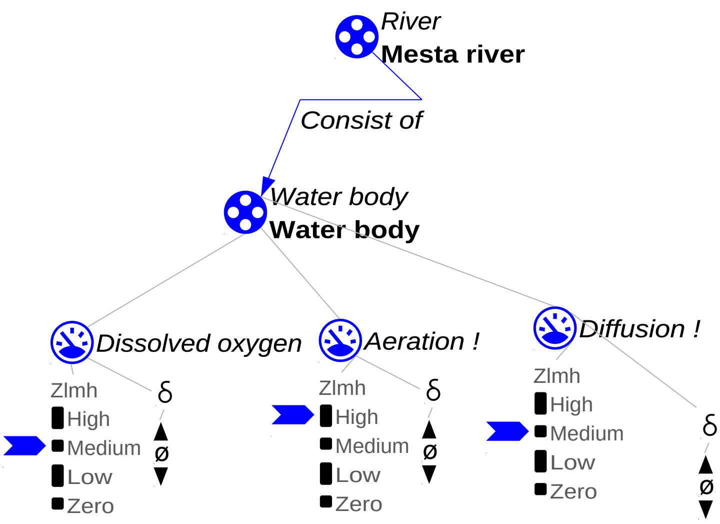



*Figure 45.Scenario 01a*“Aeration greater than Diffusion

| | |
|---|---|
| Scenario name | Sc 01 a Aeration greater than Diffusion |
| Full simulation | 2 states |
| Initial states | [1] |
| End states | [2] |
| Relevant behavior path | [1→2] |
| Behavior description | When the process Aeration is high and stable and Diffusion is *medium* and *stable* (Aeration is greater than diffusion), the Amount of DO increasing – medium to high in state 2. |

Table 4: Simulation summary: Scenario 01a Aeration greater than diffusion

Fast moving of water masses mixes air and water and thus aerate (saturate with oxygen) river water

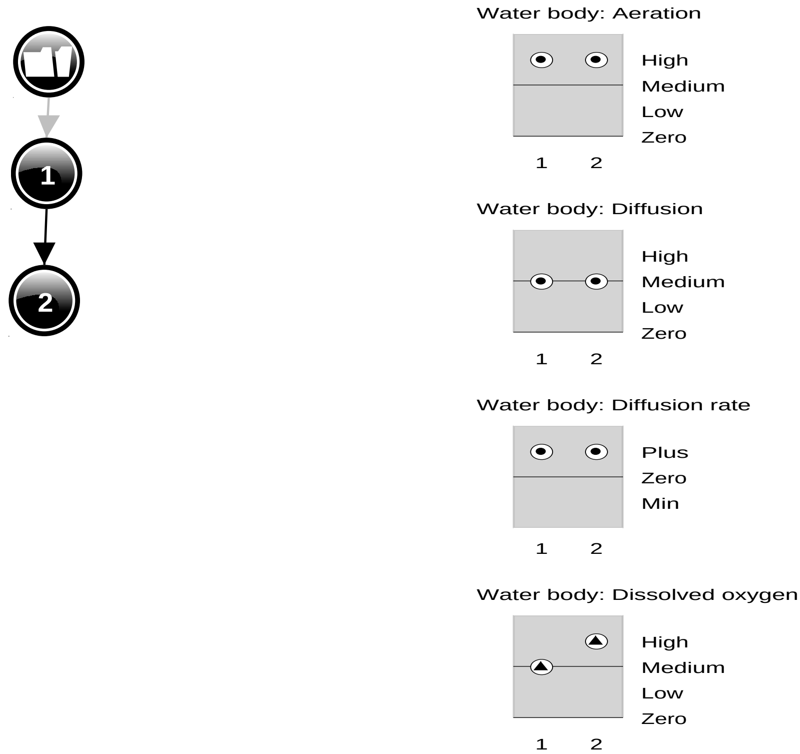



*Figure 46.Scenario 01a*"Aeration greater than Diffusion"- *Simulation and Value history*

### 5.1.3 Sc01b Aeration smaller than diffusion

When in some circumstance flow/velocity of the river is diminishing as in cases of stretches with slow flow/velocity and/or water abstraction, the aeration is decreasing. In this initial conditions, in summer when the temperature is high (day noon hours) and water accumulate some amount of heat, the process of diffusion of oxygen in the atmosphere become intensive and greater than aeration. This decreases the amount of DO in the stream, which could jeopardize the stream ecosystem biota.

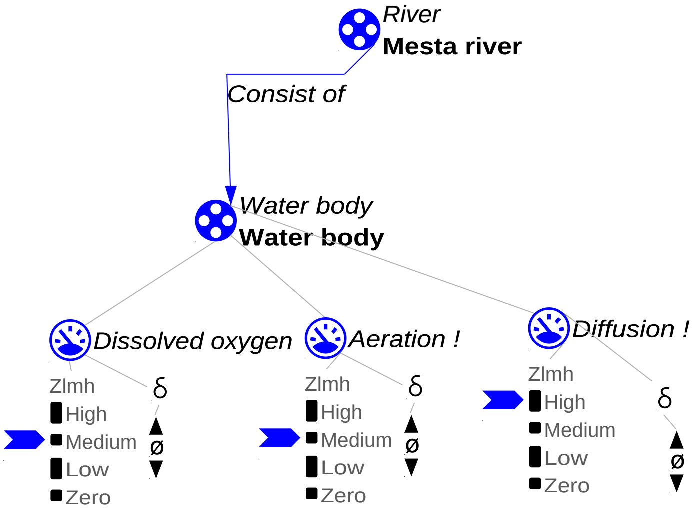



*Figure 47. Scenario 01 b* "Aeration smaller than Diffusion"

| | |
|---|---|
| Scenario name | Sc 01 b Aeration smaller than Diffusion |
| Full simulation | 2 states |
| Initial states | [1] |
| End states | [2] |
| Relevant behavior path | [1→2] |
| Behavior description | When the process Aeration is *medium* and *stable* and Diffusion is *high* and *stable* (Aeration is smaller than diffusion), the Amount of DO decreasing. Medium to low in state 2. |

Table 5: Simulation summary: Scenario 01a Aeration greater than diffusion

The intensification of reverse diffusion process (high temperatures) increases the amount of DO, going to the atmosphere. This loses of oxygen in water bodies can be dangerous for biota.

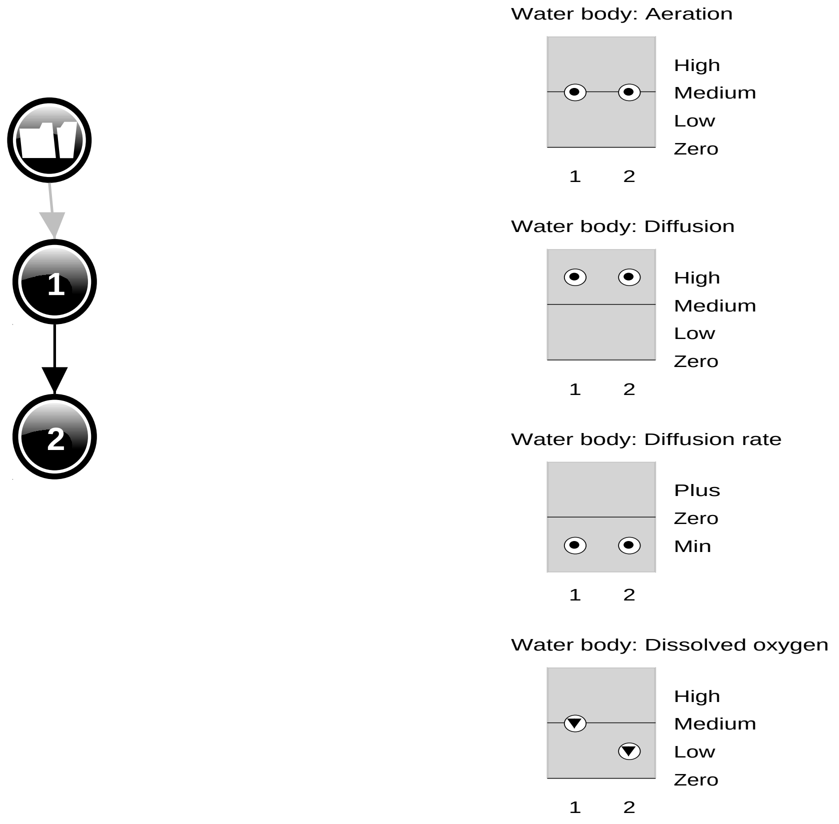



*Figure 48 Scenario 01 b* “Aeration smaller than Diffusion”- *Simulation and Value history*

### 5.1.4 Sc 01c Aeration is increasing and Scenario 01d Diffusion is increasing.

These two scenarios have the same view. The only difference is that in scenario 01c Aeration is increasing and diffusion is stable. In the scenario 01d the diffusion is increasing and aeration is stable.

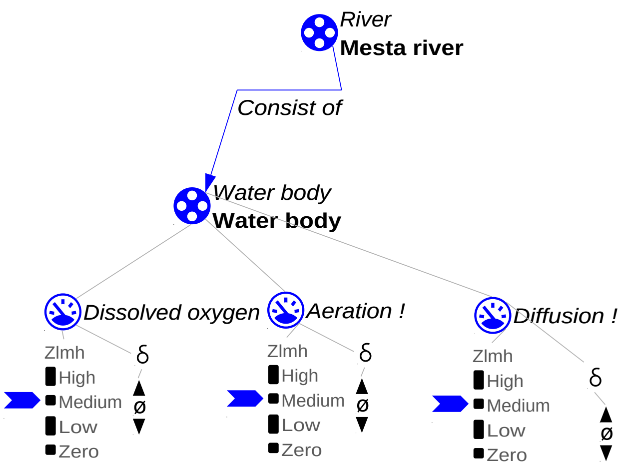



*Figure 49. Scenario 01 c “Aeration is increasing” and Scenario 01d*“Diffusion is increasing

| Scenario name | Sc 01 c Aeration is increasing | Sc 01 d Diffusion is increasing |
|---|---|---|
| Full simulation | 3 states | 3 states |
| Initial states | [1] | [1] |
| End states | [3] | [3] |
| Relevant behavior path | [1→2→3] | [1→2→3] |
| Behavior description | When the process Aeration is *medium* and *increasing* and Diffusion is *medium* and *stable* (Aeration is increasing), the Amount of DO also increase – Stable in state 1 to medium increasing in state 2 to high increasing to state 3. We can see this phenomenon when we have an extra amount of water ( precipitations) | When the process of aeration is *medium* and *stable* and Diffusion is *medium* and *high* (Diffusion is increasing), the Amount of DO decrease. Stable in state 1 to medium decreasing in state2 to low decreasing in state 3. |

Table 6: Simulation summary: Scenario 01a Aeration greater than diffusion

These scenarios show same simulation; only difference is the behavior of DO Figure 50. In simulation of scenario 1c Amount of DO increases due to intensity of process of Aeration. The opposite we see in simulation of scenario 1d, Amount of DO decrease due to intensity of the process of reverse diffusion.

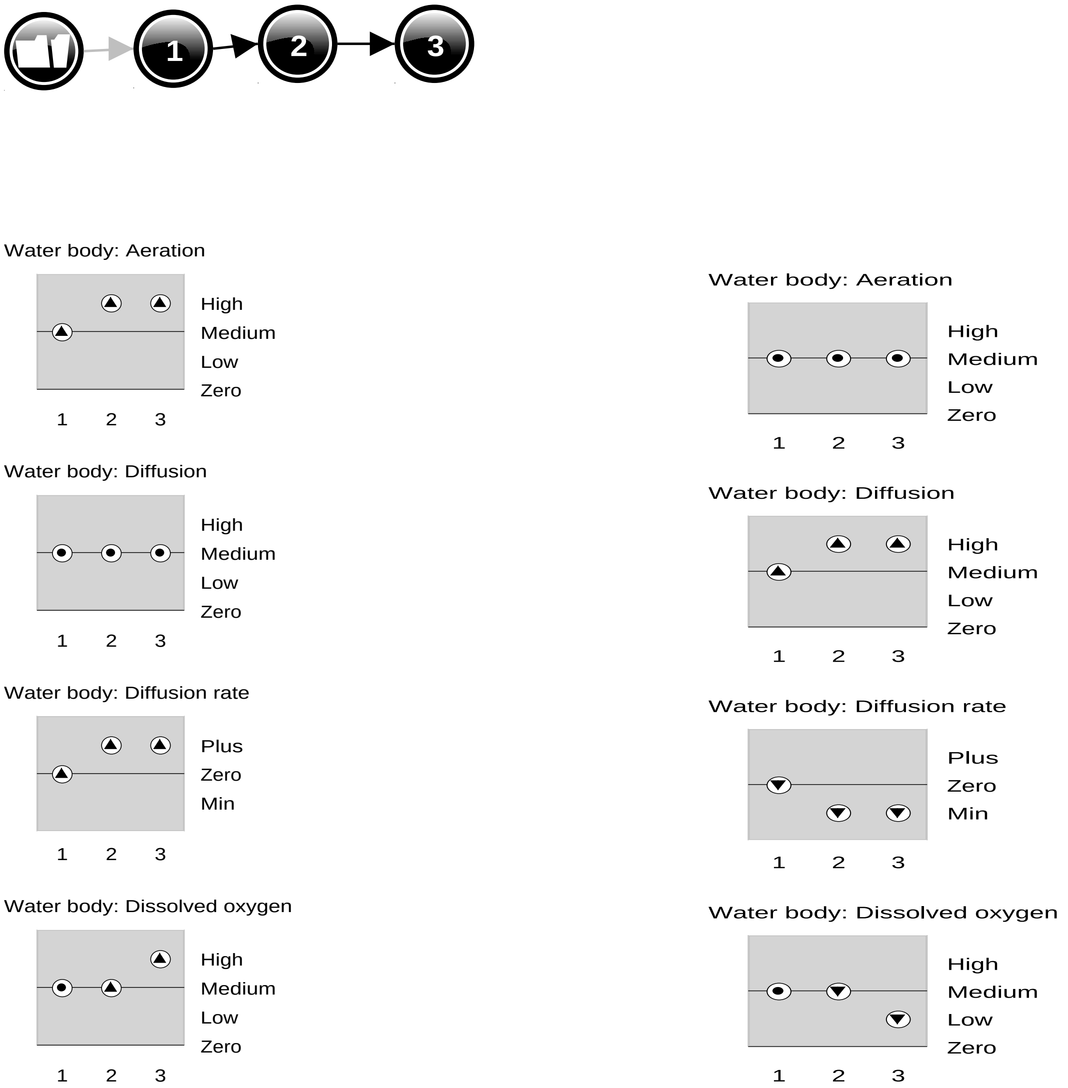



*Figure 50. Scenario 01 c “Aeration is increasing” and Scenario 01d*“Diffusion is increasing” ”- *Simulation and Value history*

### 5.1.5 Sc 02 Water abstraction agent

Water abstraction is a very common practice of taking out from water bodies and re-direction of some water amounts through water supply systems for further use by humans. Decreasing water discharge in natural water bodies affects significantly all physical and biological processes which are responsible for setting up the oxygen balance and thus may affect negatively the ecological state and ecosystem health of water bodies downstream the abstraction point.

The process is active in case of water abstraction for human needs. The effects of water abstraction depend on the amount of water abstracted. The greater is the abstracted amount, the less is the residual water in affected water body and consequent effects on ecological state and ecosystem health relevant to the physical and biological processes responsible for DO balance in a water body. Water abstraction influences aeration. Aeration is collective quantity, related to the flow/velocity of a stream. The decreasing of residual water in stream, decreases flow/velocity of river, thus diminishing capacity of water to mix the air – which is presented by aeration.

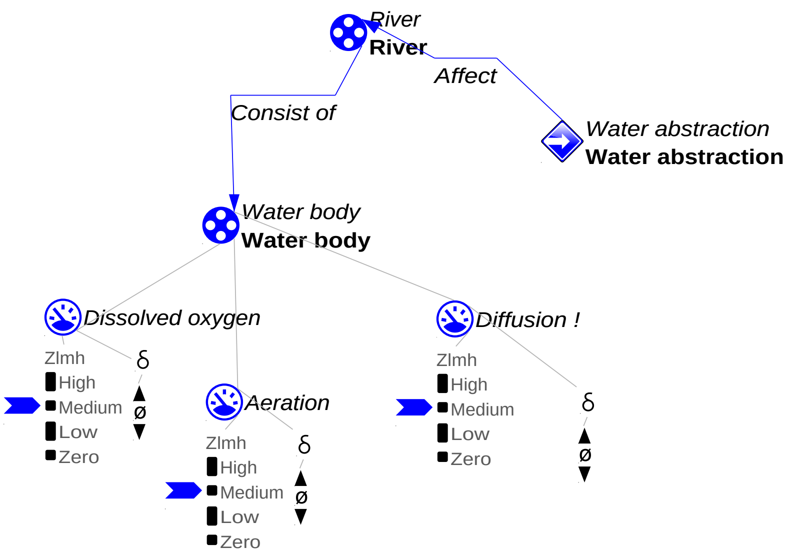



*Figure 51.* Scenario 02 “Water abstraction agent”

| | |
|---|---|
| Scenario name | Sc 02 Water abstraction agent |
| Full simulation | 3 states |
| Initial states | [1] |
| End states | [3] |
| Relevant behavior path | [1→2→3] |
| Behavior description | Amount of DO decrease. Medium and stable in state 1 to medium decreasing in state 2 to low and decreasing in state 3. Aeration and Diffusion rate are also decreasing – medium and decreasing in state 1 to low and decreasing in state 2 to low and decreasing in state 3. |

Table 7: Simulation summary: Scenario 01a Aeration greater than diffusion

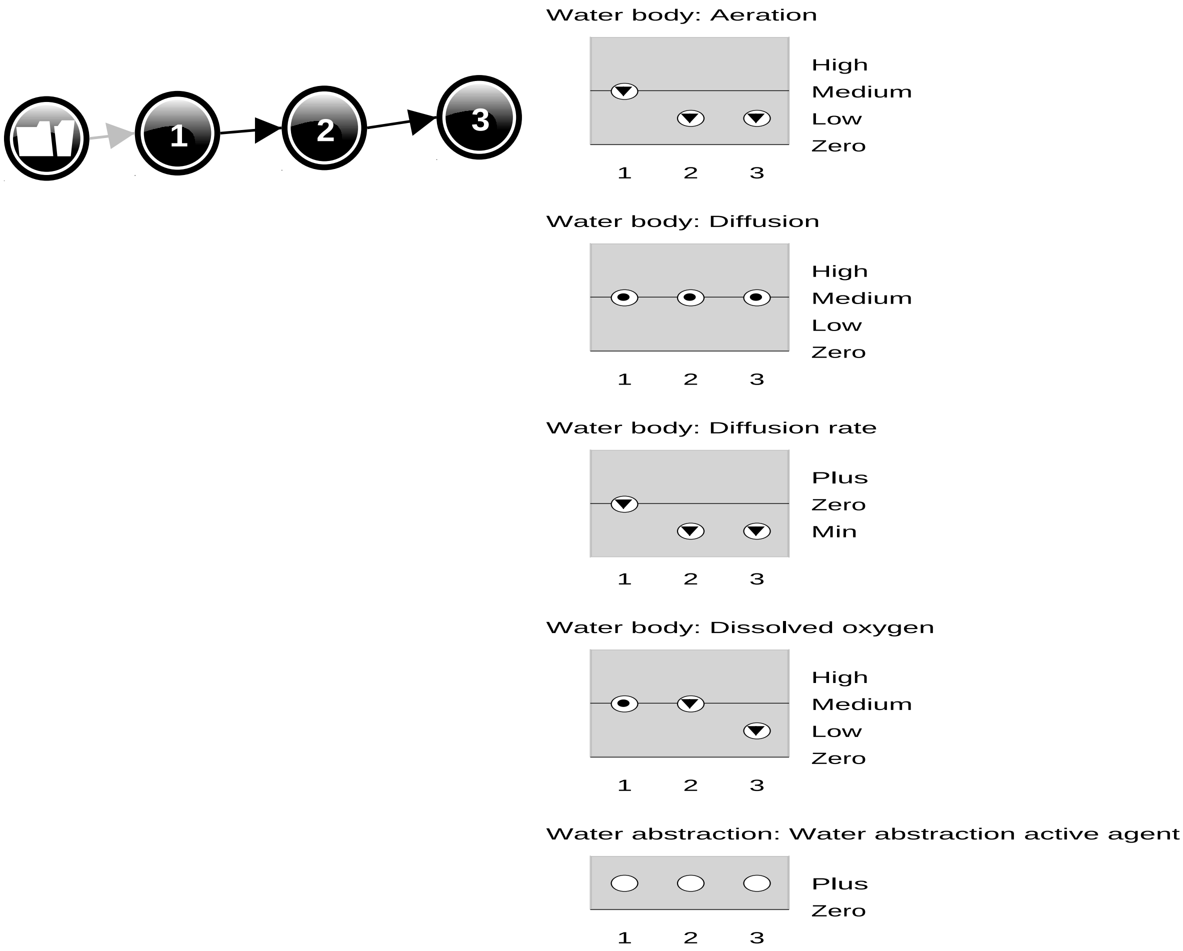



*Figure 52.* Scenario 02 “Water abstraction agent”- *Simulation and Value history*

## *5.2 Second types of simulations concerning whole river system - both physical and biological. The processes of Respiration and photosynthesis show the same behavior like processes of Aeration and Diffusion.*

### 5.2.1 Sc 03 River Mesta Oxygen Behavior

This is complex scenario which shows, the behavior of river system under influence of biological and physical processes. Here we include the influence of processes of Respiration and Photosynthesis. Scenario is constructed of 9 quantities and there is one assumption that process of Respiration and Photosynthesis are equal. The Processes of Aeration (*medium stable*) and Diffusion (stable *and medium*) equal. There are no negatively influences concerning amount of suspended solids (no erosion influences and Amount of suspended solids is *low* and *stable*) and Amount of POM is low which shows that there is no intensive organic pollution. The other additional processes like grazing, decomposition are in normal condition, to not change the equilibrium.

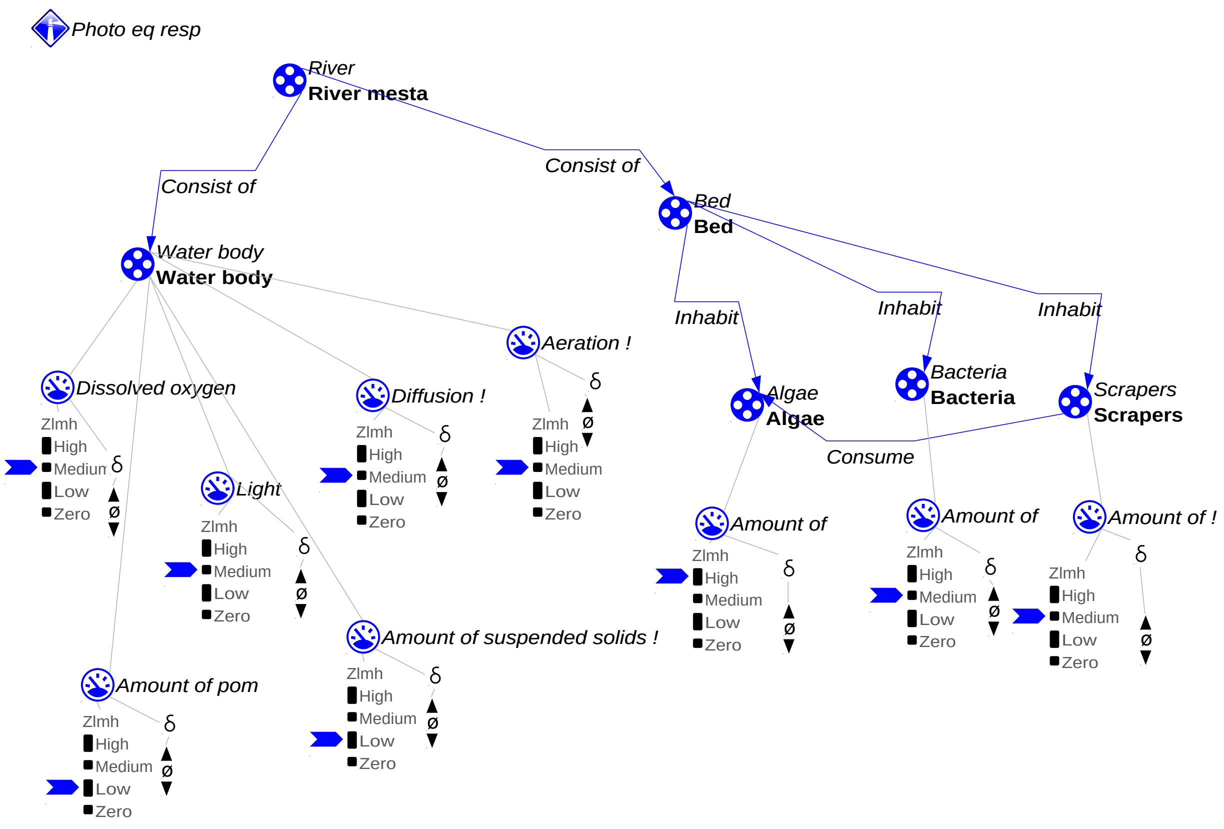



*Figure 53.* Scenario 03 “River Mesta oxygen behavior”

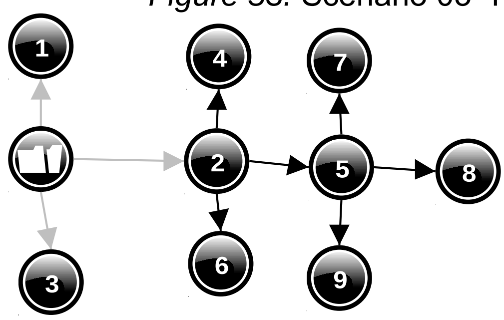



*Figure 54a.* Scenario 03 “River Mesta oxygen behavior”- Simulation

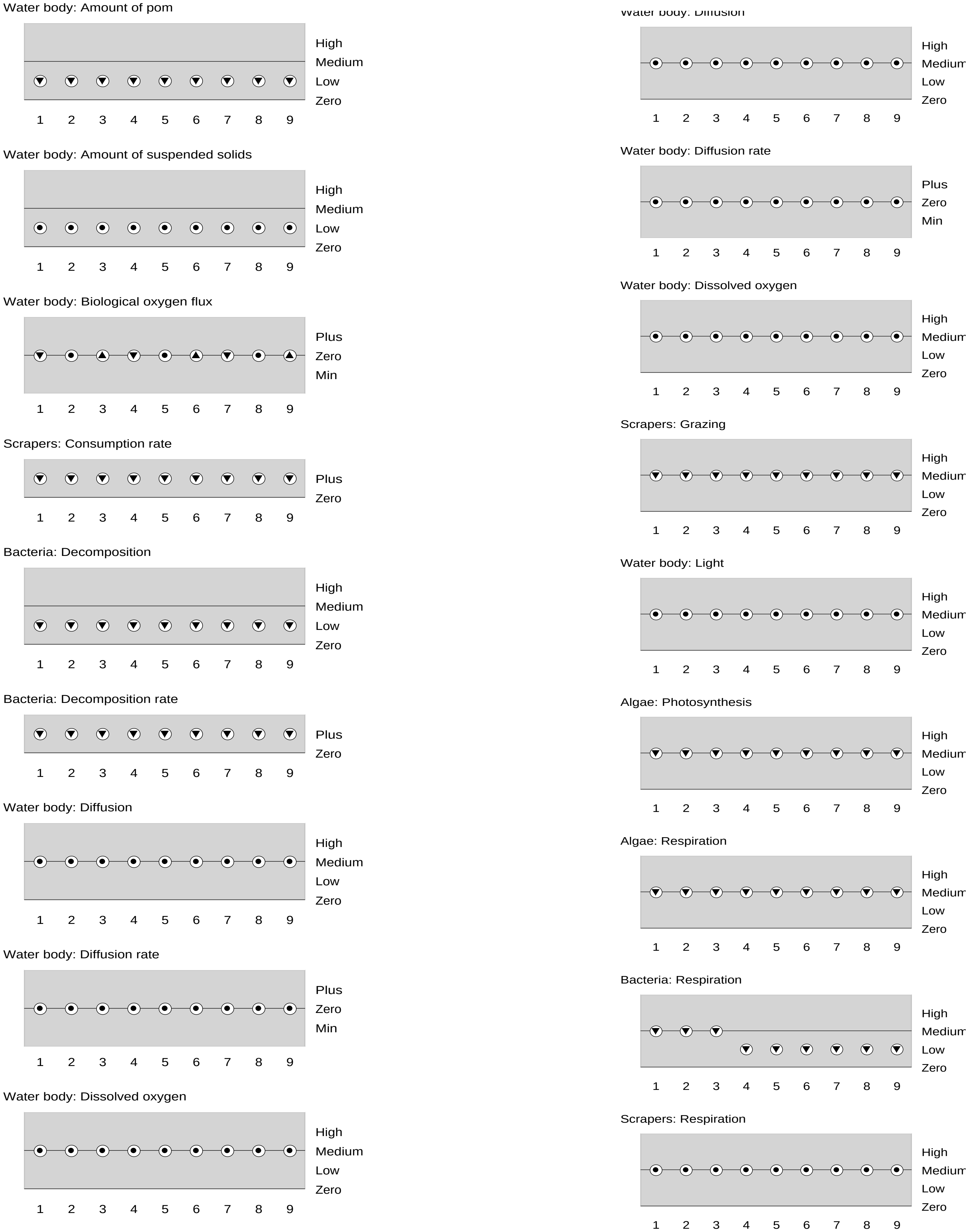



*Figure 54b.* Scenario 03 “River Mesta oxygen behavior ”- Value history

| | |
|---|---|
| Scenario name | Sc 03 River Mesta oxygen behaviour |
| Full simulation | 9 states |
| Initial states | [1] |
| End states | [1,3,4,6,7,8,9] |
| Relevant behavior path | [2→5→8] |
| Behavior description | The processes of Aeration and Diffusion are equal ( *medium* and *stable*). There is an assumption that processes of Respiration and photosynthesis are equal. The Amount of dissolved oxygen doesn't change – *medium* and *stable*. This quantity shows stable conditions. Simulation shows the influence of different environmental factor of intensity of processes of Respiration ( amount of DO) and Photosynthesis ( Light). Process of Grazing influence and decrease the Amount of algae. Process of Bacterial degradation influence and decrease the Amount of Particulate organic matter which reduce pollution. Amount of suspended solids is low and stable, this mean that light is not influenced of this parameter. |

Table 8: Simulation summary: Scenario 03 "River Mesta oxygen behavior"

### 5.2.2 Sc 03a daily conditions

Another complex scenario which have one main goal. There is an evident difference between amount of DO in day and night. Daily conditions are described with intensive process of photosynthesis, which is greater than respiration, and because the temperatures during the day are high compared with night, there is an intensive process of reverse diffusion. The conditions related with Amount of suspended solids and amount of particulate organic matter ( related with the amount of bacteria and available light ) are the same like in the previous scenario. There is an Assumption which shows that Photosynthesis is greater than respiration.

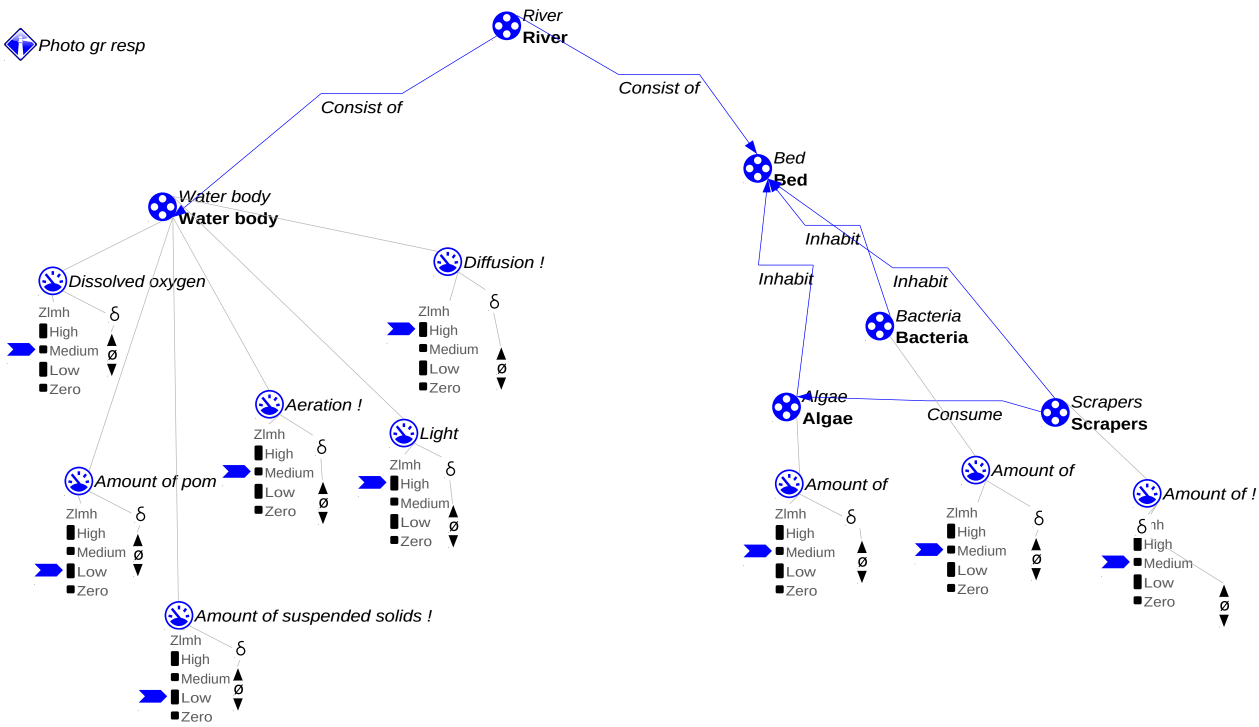



*Figure 55.* Scenario 03a “Daily conditions”

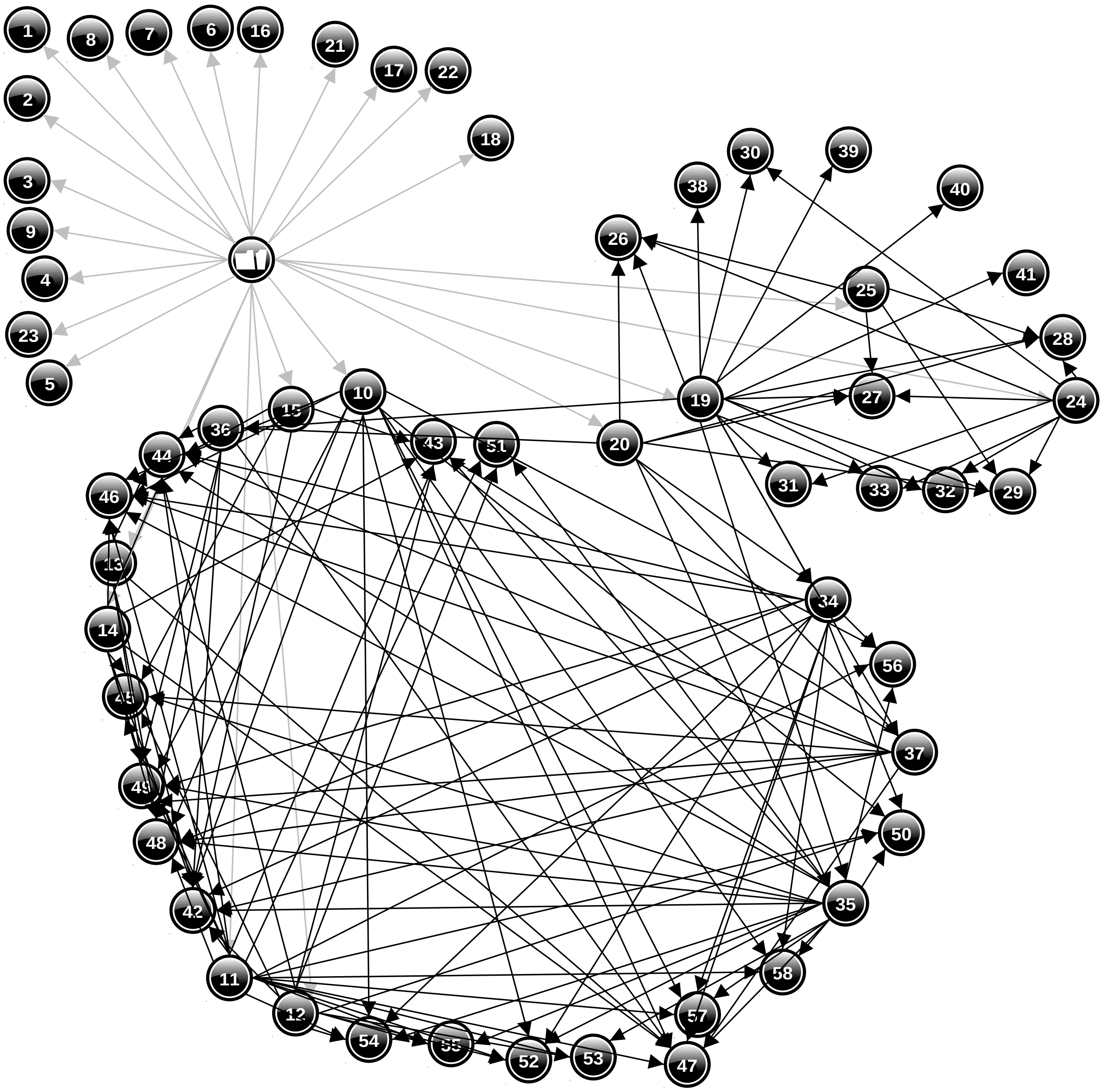



*Figure 56a.* Scenario 03a "Daily conditions" - Simulation


Figure 56b. Scenario 03a "Daily conditions" – value history of main biological and physical processes

| | |
|---|---|
| Scenario name | Sc 03a Daily conditions |
| Full simulation | 58 states |
| Initial states | 25 states |
| End states | Simulation with many end states |
| Relevant behavior path | No path |
| Behavior description | Diffusion is *high* and *stable*, Aeration is *medium* and *stable* ( diffusion is greater than aeration). There is an assumption that Photosynthesis is greater than Respiration. We see two opposite processes which change the equilibrium of dissolved oxygen. Photosynthesis increase the amount of DO, while diffusion diminish oxygen concentration. |

Table 9: Simulation summary: Scenario 03a " Daily conditions"

### 5.2.3 Sc 03b Night condition

One of the main characteristics of the night conditions is the lack of light, so there is total decreasing of the Photosynthesis. On the other hand the temperatures of the water decreases during the night so the process of Aeration is greater then process of diffusion.

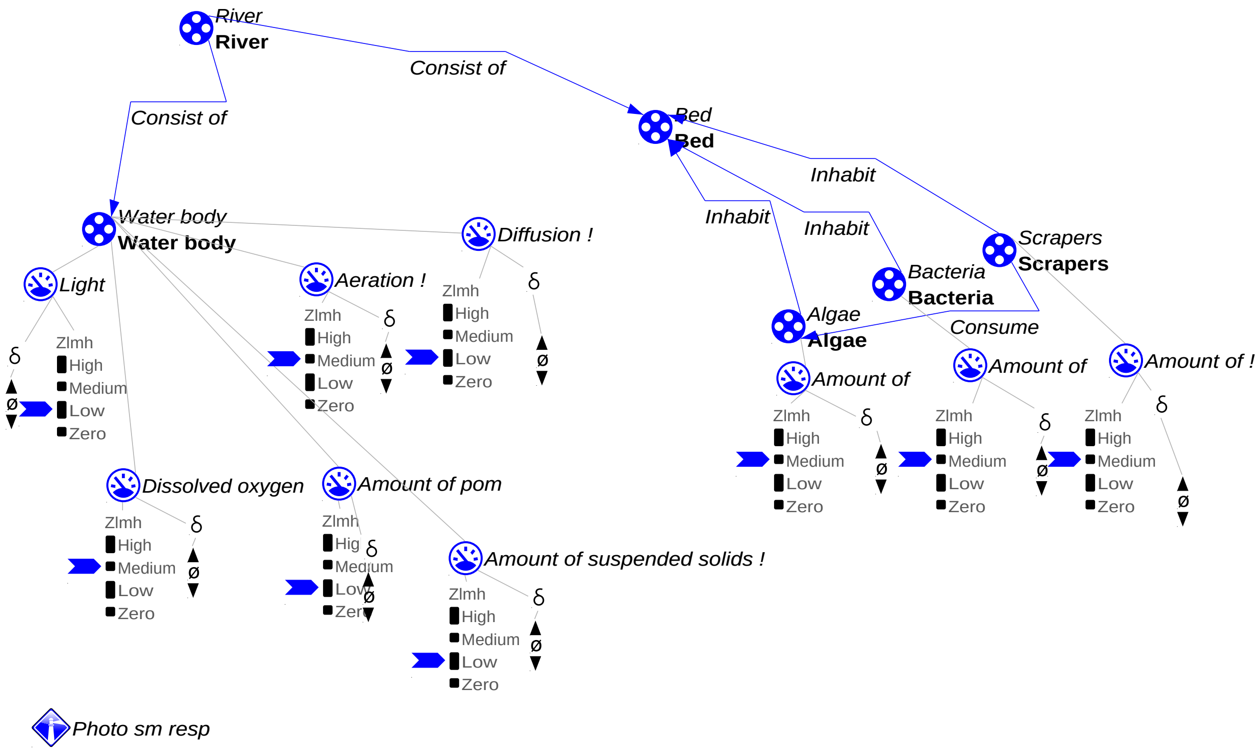
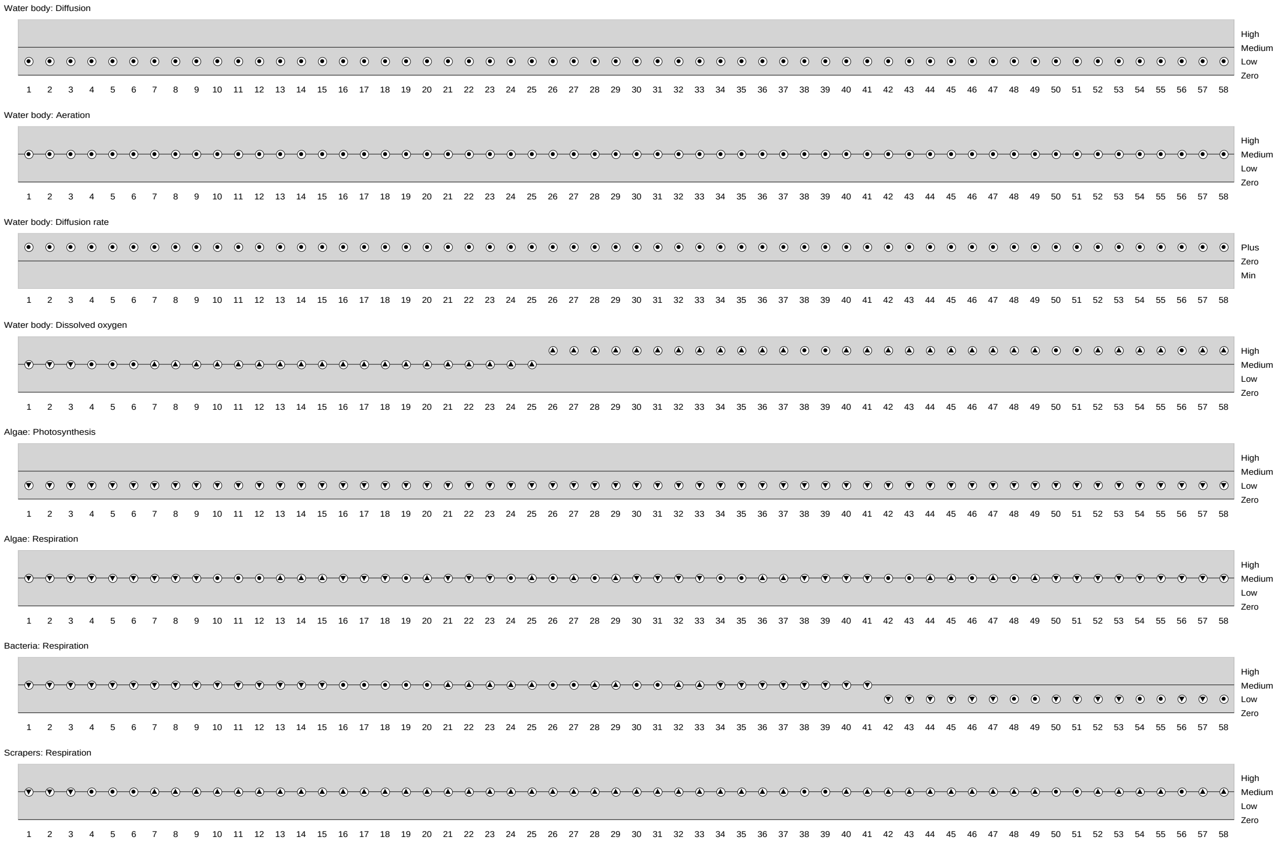



*Figure 57.* Scenario 03a "Night condition"




| | |
|---|---|
| Scenario name | Sc 03b Night conditions |
| Full simulation | 58 states |
| Initial states | 25 states |
| End states | Simulation with many end states |
| Relevant behavior path | No path |
| Behavior description | Aeration is *medium* and *stable*, Diffusion is *low* and *stable*. There is an assumption that process of Respiration is greater than photosynthesis. We see two opposite processes which change the equilibrium of dissolved oxygen. Intensification of Respiration decreases the Amount of DO. In the other hand there is an intensive process of Aeration, which saturate water with oxygen. |

Table 10: Simulation summary: Scenario 03b “ Night conditions”

### 5.2.4 Sc 04 Uncontrolled water abstraction night

Like in the previous scenarios nigh conditions are characterized with lack of light, so there is total decreasing of the rate of Photosynthesis. When we have permanent water abstraction, thus can decrease the capacity of the process of Aeration (in some extent river stretch). There is no other negative influence, Amount of POM is low, and witch determines low Amount of bacteria, whit low Decomposition rate. Amount of suspended solids is low and stable. There is an assumption that Photosynthesis is smaller than respiration.

Simulation (fig 59) is simple; there is tree initial and no end states. In the tree states Amount of DO decrease. This simulation shows that abstraction of water influence negatively stream ecosystem equilibrium.

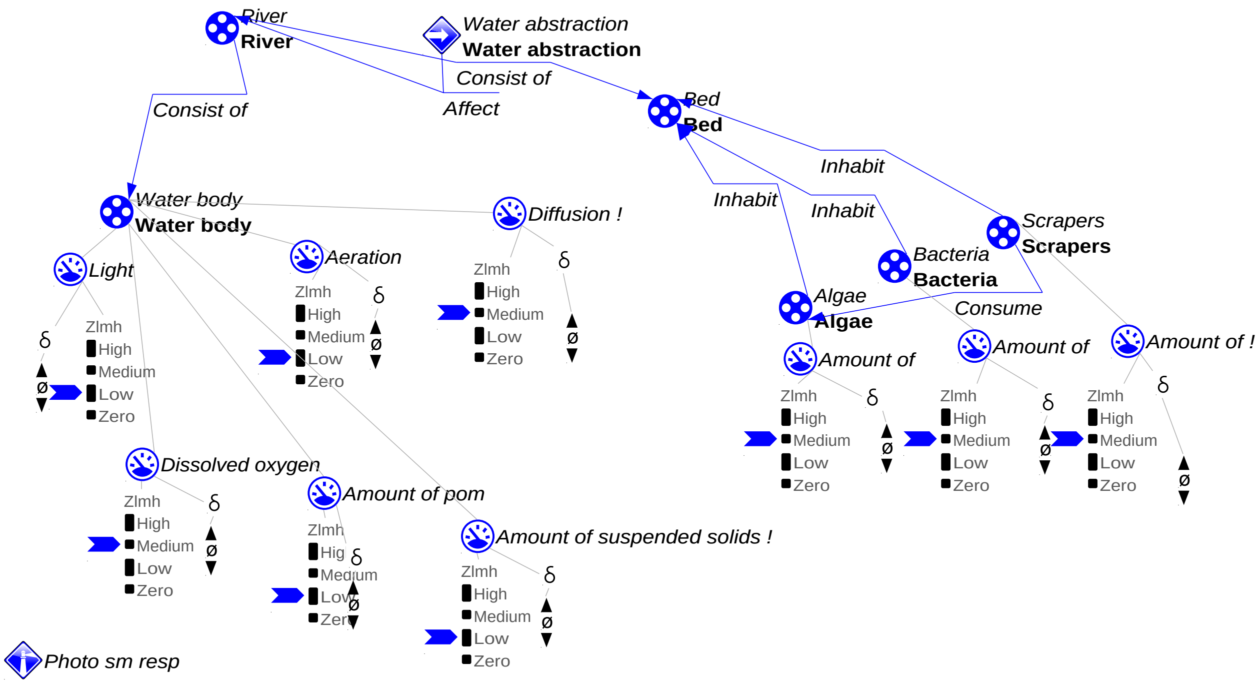



*Figure 58.* Scenario 04 “Uncontrolled water abstraction night”

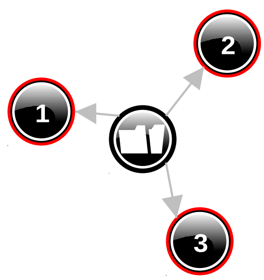



*Figure 59 a.* Scenario 04 “Uncontrolled water abstraction night” - Simulation

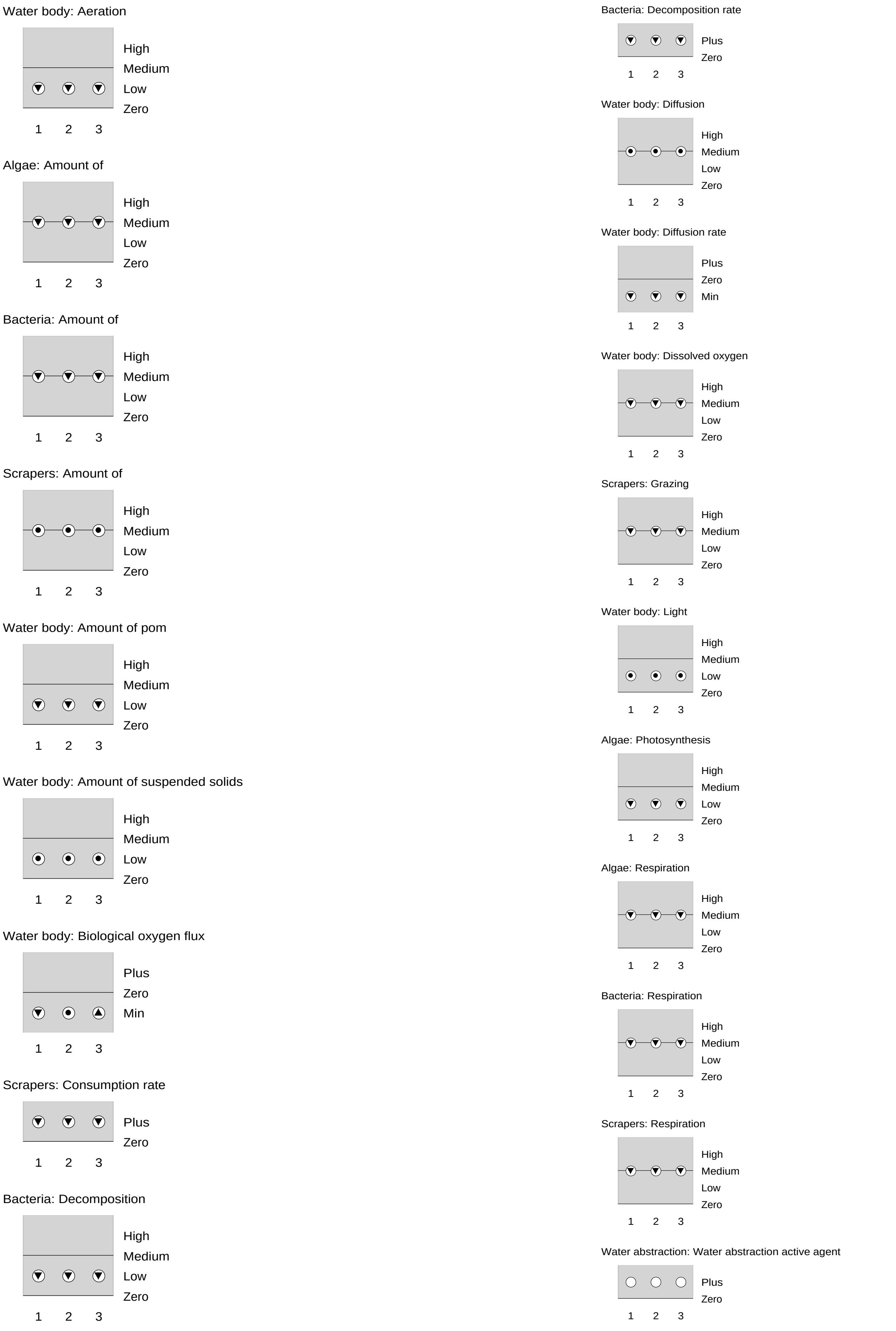



*Figure 59 b.* Scenario 04 “Uncontrolled water abstraction night” - Value history

| | |
|---|---|
| Scenario name | Sc 04 Uncontrolled water abstraction night |
| Full simulation | 3 states |
| Initial states | [1,2,3] |
| End states | No end states |
| Relevant behavior path | No path |
| Behavior description | Aeration Is *low*, Diffusion is *medium* and *stable*, and Photosynthesis is smaller than respiration because of lack of light. Because of the influence of two process with same direction amount of DO decrease. In the all states Amount of DO is medium and decreasing. |

Table 11: Simulation summary: Scenario 04 "Uncontrolled water abstraction night"

### 5.2.5 Sc 05 Erosion

Process of removal of soil particles from upper horizons by precipitation and wind, resulting in reduction of soil fertility and loss of essential nutrients for terrestrial plants. Removed particles entering the water body as suspended solids. High suspended solids loads can cause siltation of the river bed and smother algae and animals, decrease light penetration, cause stress to aquatic organisms and reduce photosynthesis. This scenario shows the negative influence of Turbidity, respectively Amount of Suspended solids to light penetration, Photosynthesis, Amount of algae and Amount of DO. Algae are food for Scrapers, the decrease of Amount of algae, decrease Amount of scrapers. To show negative effect of erosion there is an assumption that process of Respiration and Photosynthesis are equal.

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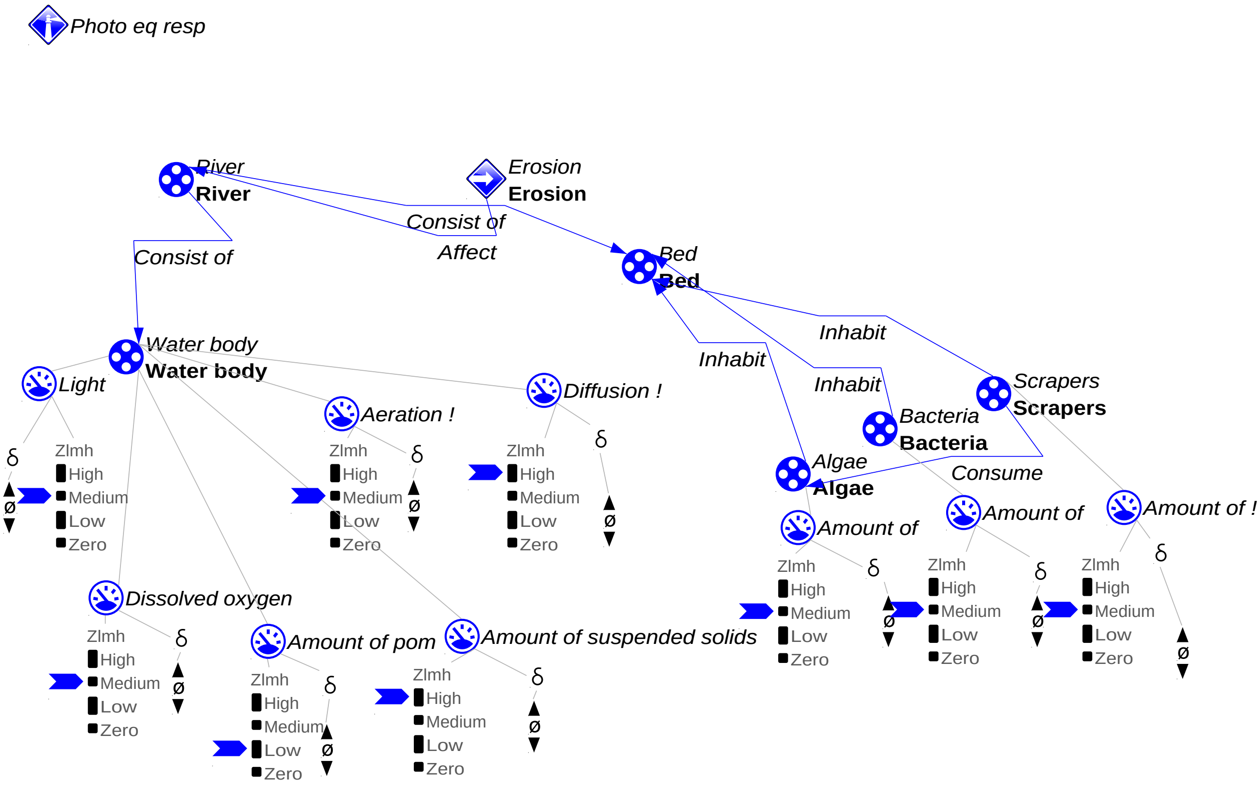



Figure 60. Scenario 05 “Erosion”

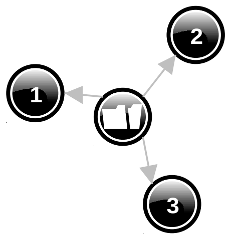



Figure 61a. Scenario 05 “Erosion”-Simulation

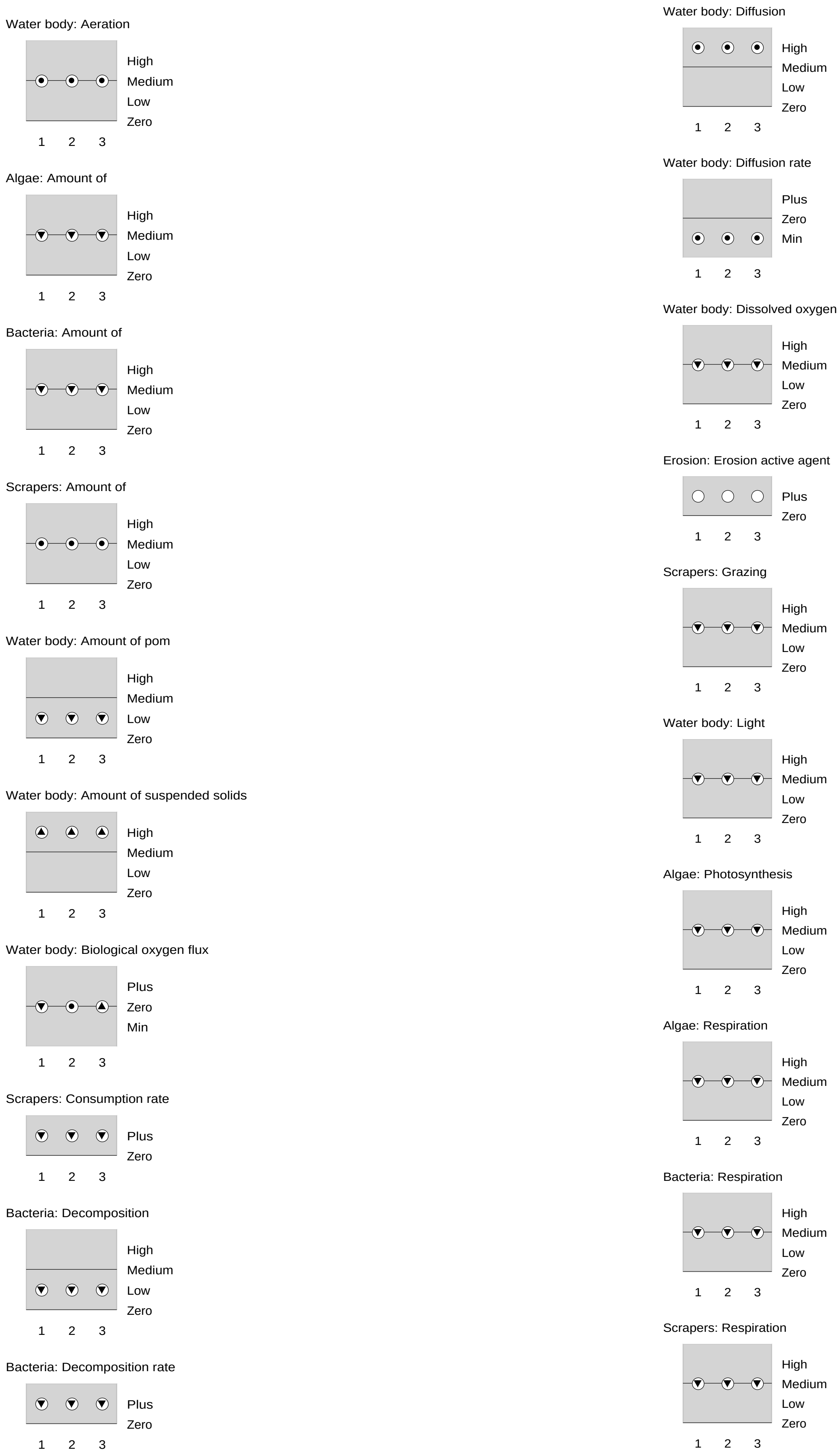



*Figure 61b. Scenario 05 “Erosion”-Value history*

| | |
|---|---|
| Scenario name | Sc 05 Erosion |
| Full simulation | 3 states |
| Initial states | [1,2,3] |
| End states | No end states |
| Relevant behavior path | No path |
| Behavior description | When we have erosion active agent, amount of DO is medium and decreasing in all states. Photosynthesis, amount of algae also decrease because of negative effect of turbidity. |

Table 12: Simulation summary: Scenario 05 “ Erosion”

### 5.2.6 Sc 06 Pollution

Pollution is a process of discharging water with extra amount of substances originated outside of water bodies, mostly from households, industries and other human activities in watershed. This extra amount of substances may change significantly the ecological status of a water body and the ecosystem health deteriorating the structure and functioning both physical and biological processes in aquatic ecosystem.

Organic pollution occurs when large quantities of organic compounds, which act as substrates for micro organisms, are released into the watercourses. Organic pollutants originate from domestic sewage, urban run-off, industrial (trade) effluent and farm wastes. When an organic polluting load is discharged into river it is gradually eliminated by activities of bacteria. This self-purification requires sufficient concentrations of oxygen, and involves the breakdown of complex organic molecules into simple inorganic molecules.

Organic pollution affects the organisms living in a stream by lowering the available oxygen in the water.

Scenario (Fig 62) is complex constructed of 9 quantities. Pollution and Amount of Particulate organic matter are available food for bacterial populations, by using oxygen they decrease Amount of DO. There is one assumption that Process of Respiration is greater than Photosynthesis.

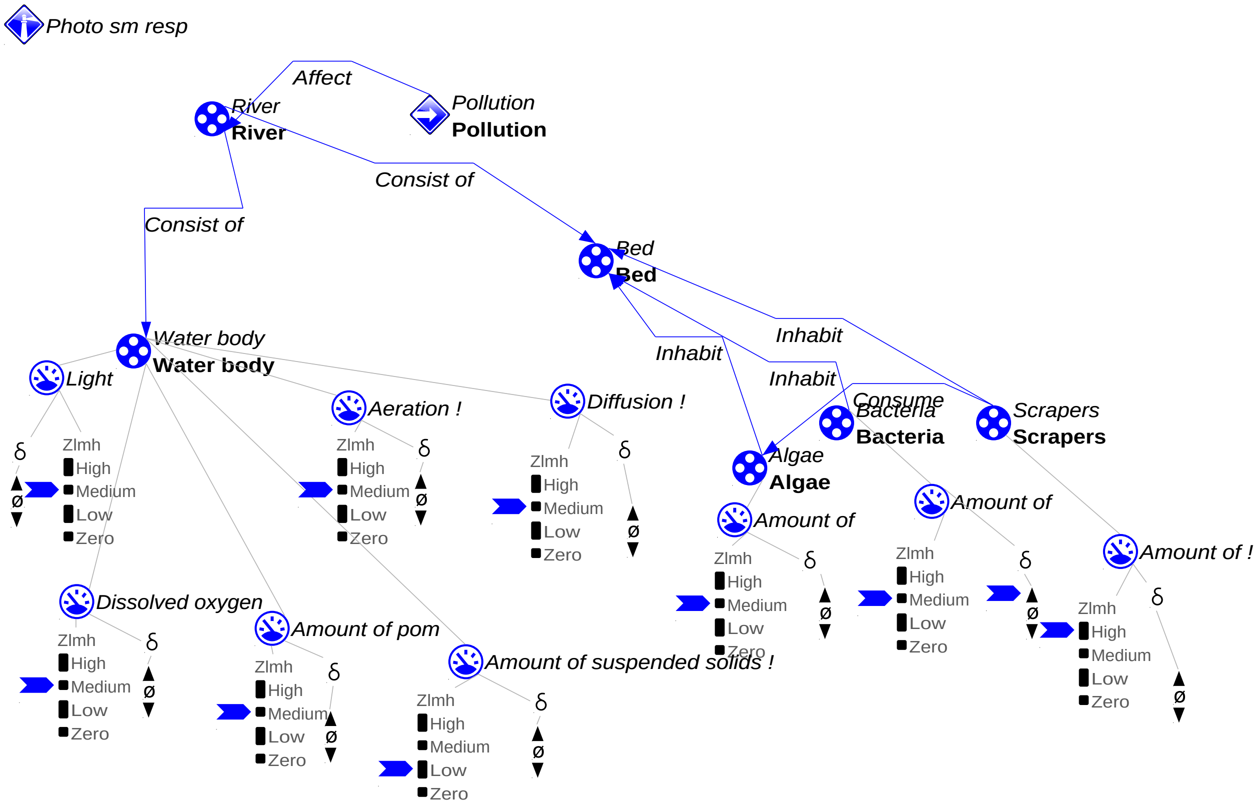



*Figure 62. Scenario 06 "Pollution"*

*Simulation consists only 9 initial states.*

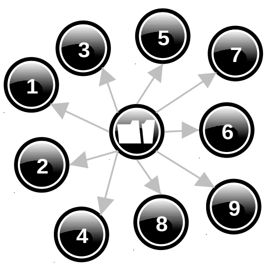



*Figure 63a. Scenario 06 "Pollution"-Simulation*

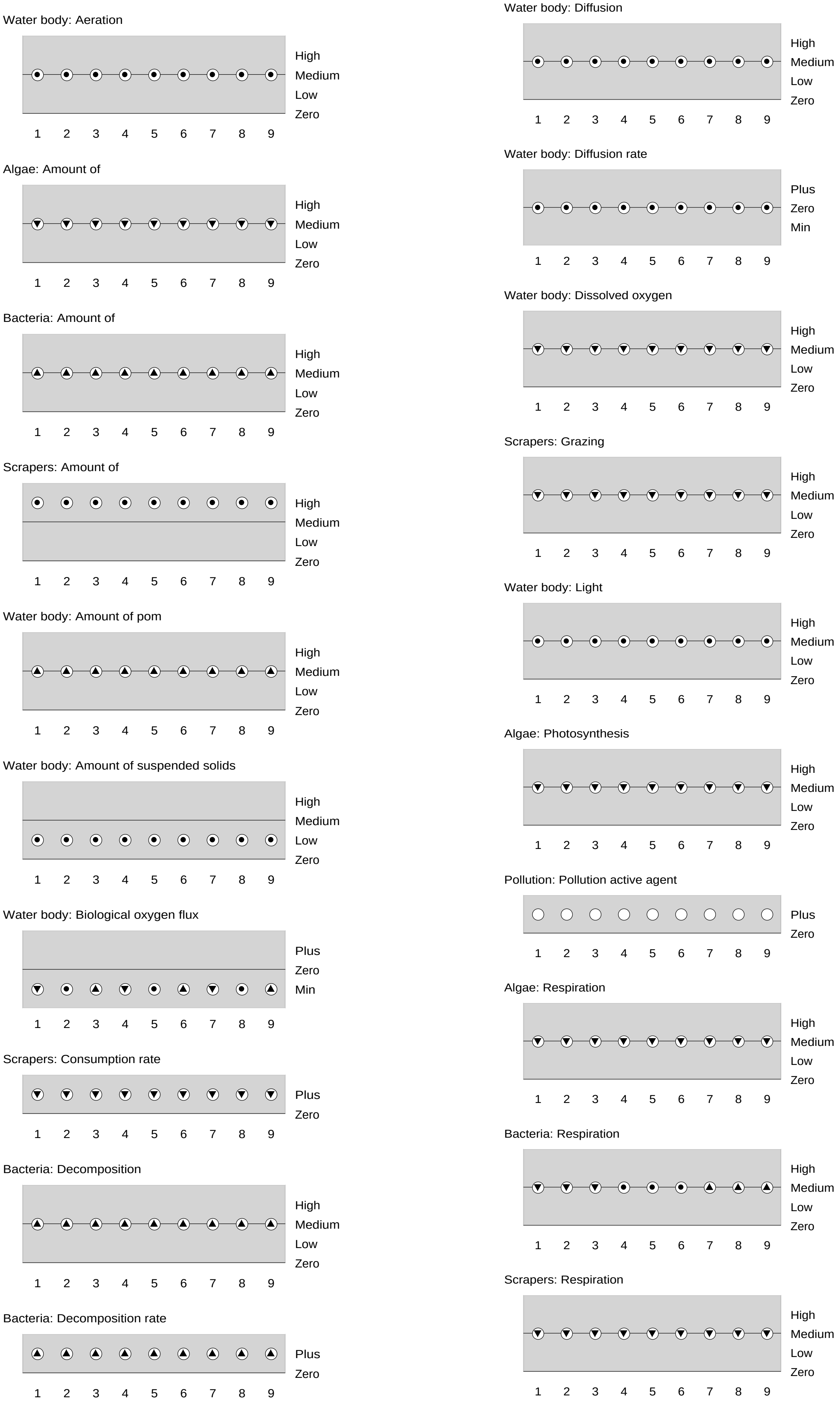



*Figure 63b. Scenario 06 "Pollution"-Value history*

| | |
|---|---|
| Scenario name | Sc 06 Pollution |
| Full simulation | 9 states |
| Initial states | [1,2,3,4,5,6,7,8,9] |
| End states | No end states |
| Relevant behavior path | No path |
| Behavior description | If we have pollution active agent, Amount of particulate organic is medium and increasing in all 9 states, Amount of bacteria is medium and increasing in all 9 states, Amount of DO is medium and decreasing in all 9 states. |

*Table 13: Simulation summary: Scenario 06 " Pollution"*

### 5.2.7 Sc 07 Pollution and erosion

This is more complex scenario ( 9 quantities and 2 agents) ( Fig 69) . There is two agents influence negatively Amount of DO – Erosion and Pollution.

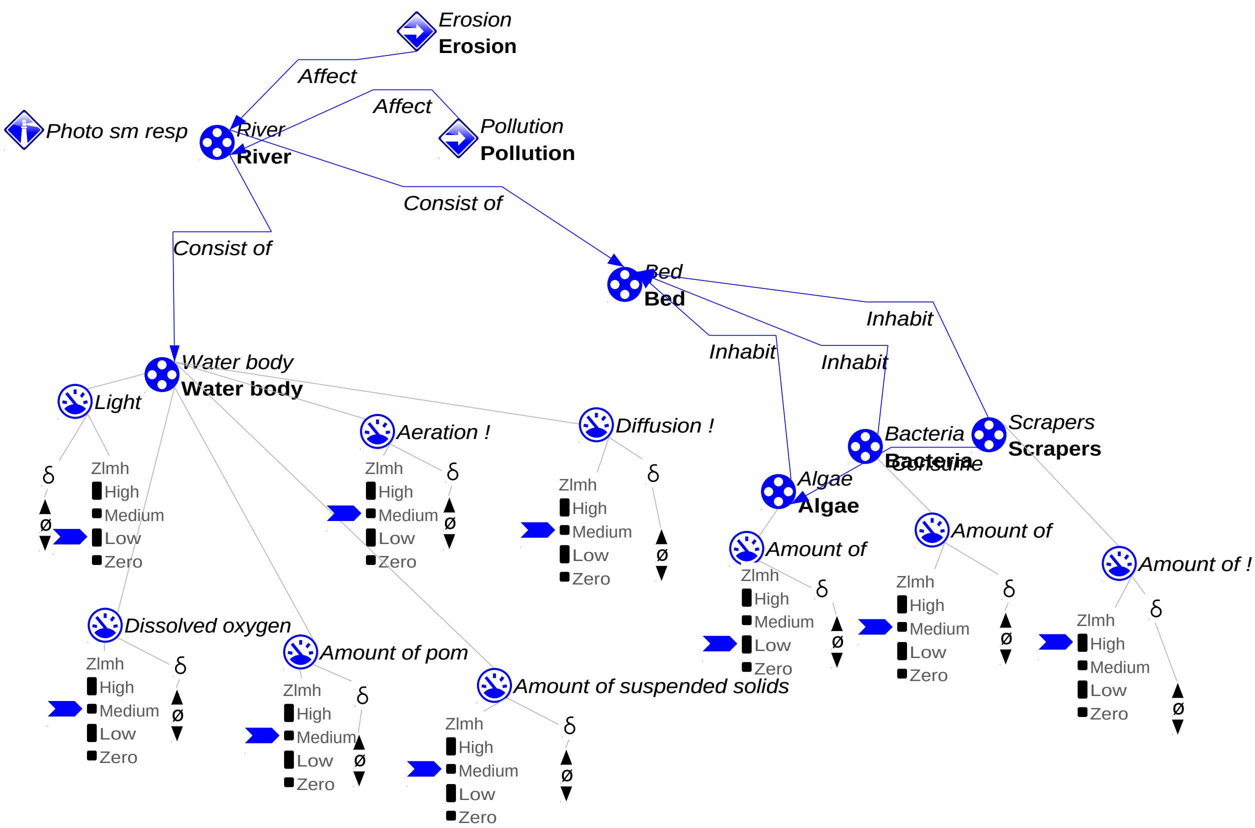



*Figure 64. Scenario 07 "Pollution and erosion"*

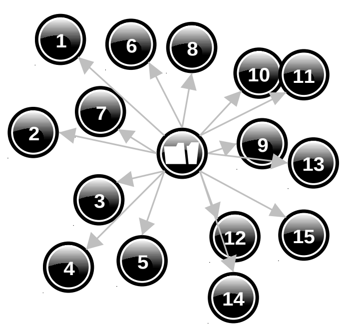



*Figure 65a. Scenario 07 "Pollution and erosion"- Simulation*

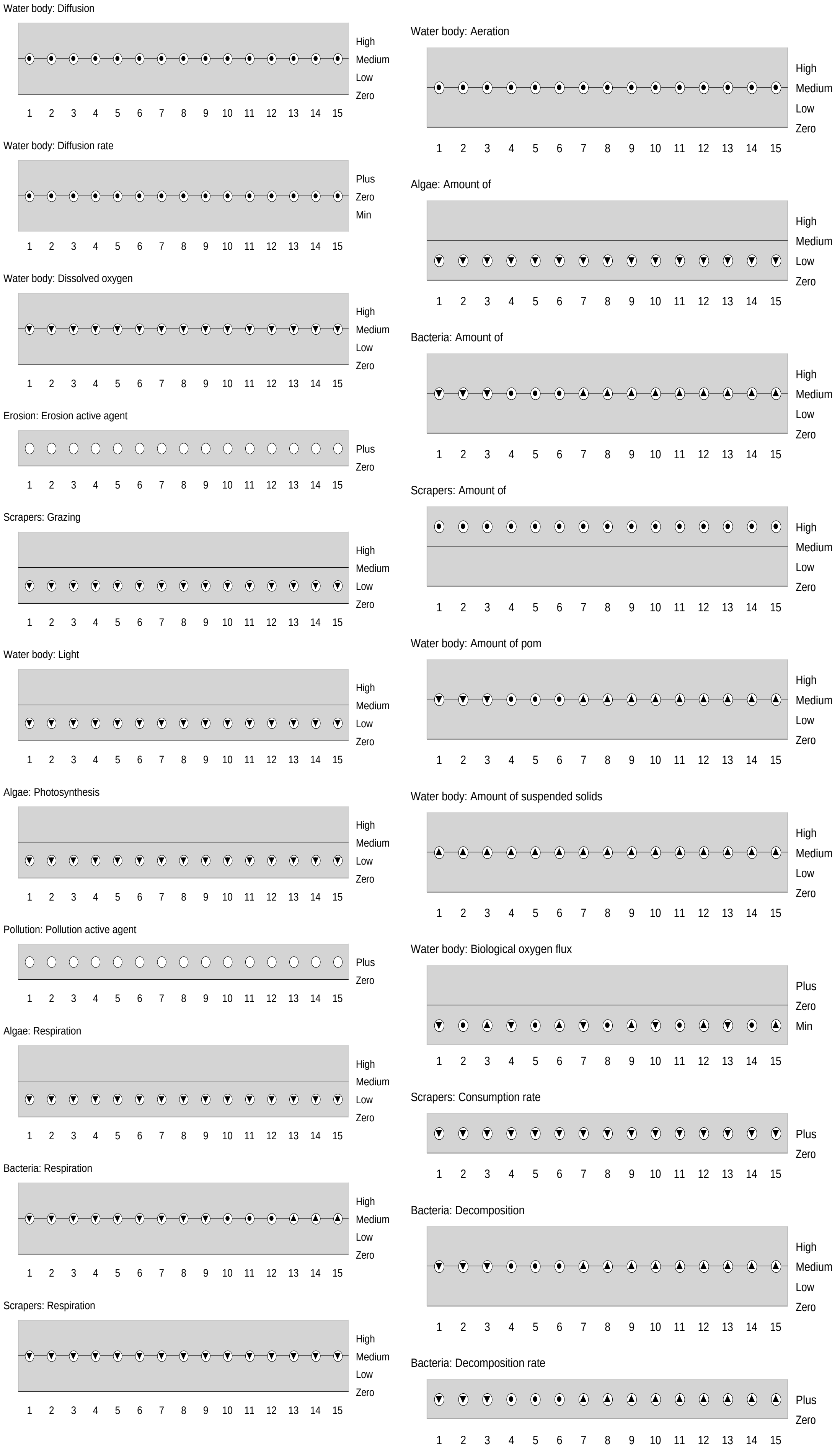



*Figure 65b. Scenario 07 “Pollution and erosion”- Value history*

| | |
|---|---|
| Scenario name | Sc 07 Pollution and erosion |
| Full simulation | 15 states |
| Initial states | [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15] |
| End states | No end states |
| Relevant behavior path | No path |
| Behavior description | Simulation is consists only of 15 initial states. In all states Amount of DO is medium and decreasing. |

*Table 14: Simulation summary: Scenario 06 " Pollution"*

### 5.2.8 Sc 08 Pollution, erosion and water abstraction

Finally we want to see the behavior of Stream ecosystem when we have all tree negative influences.

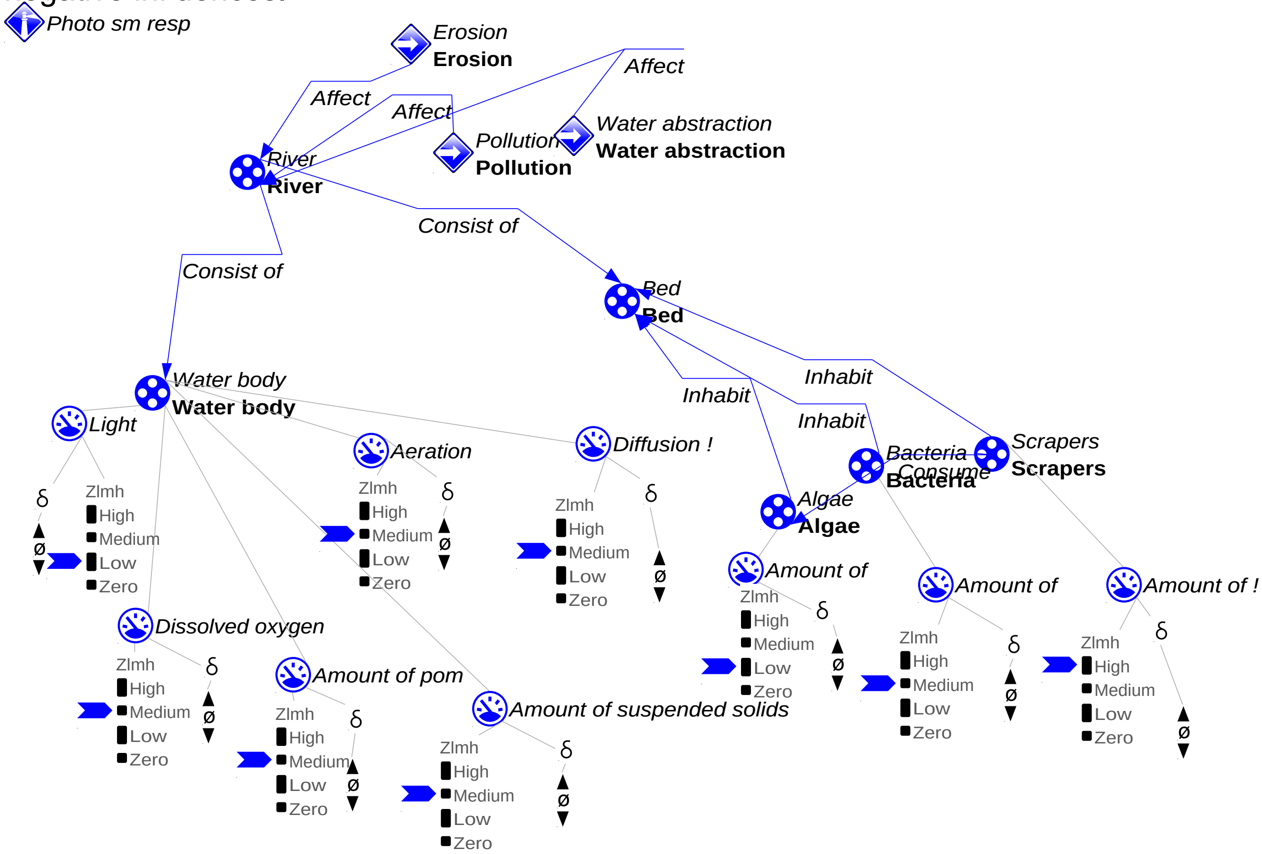



*Figure 66. Scenario 08 "Pollution, erosion and water abstraction"*

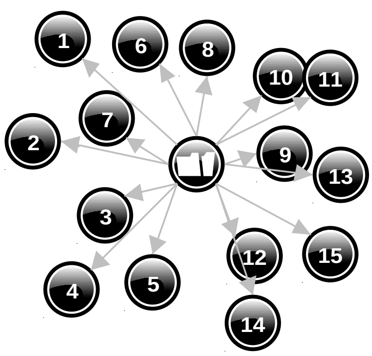
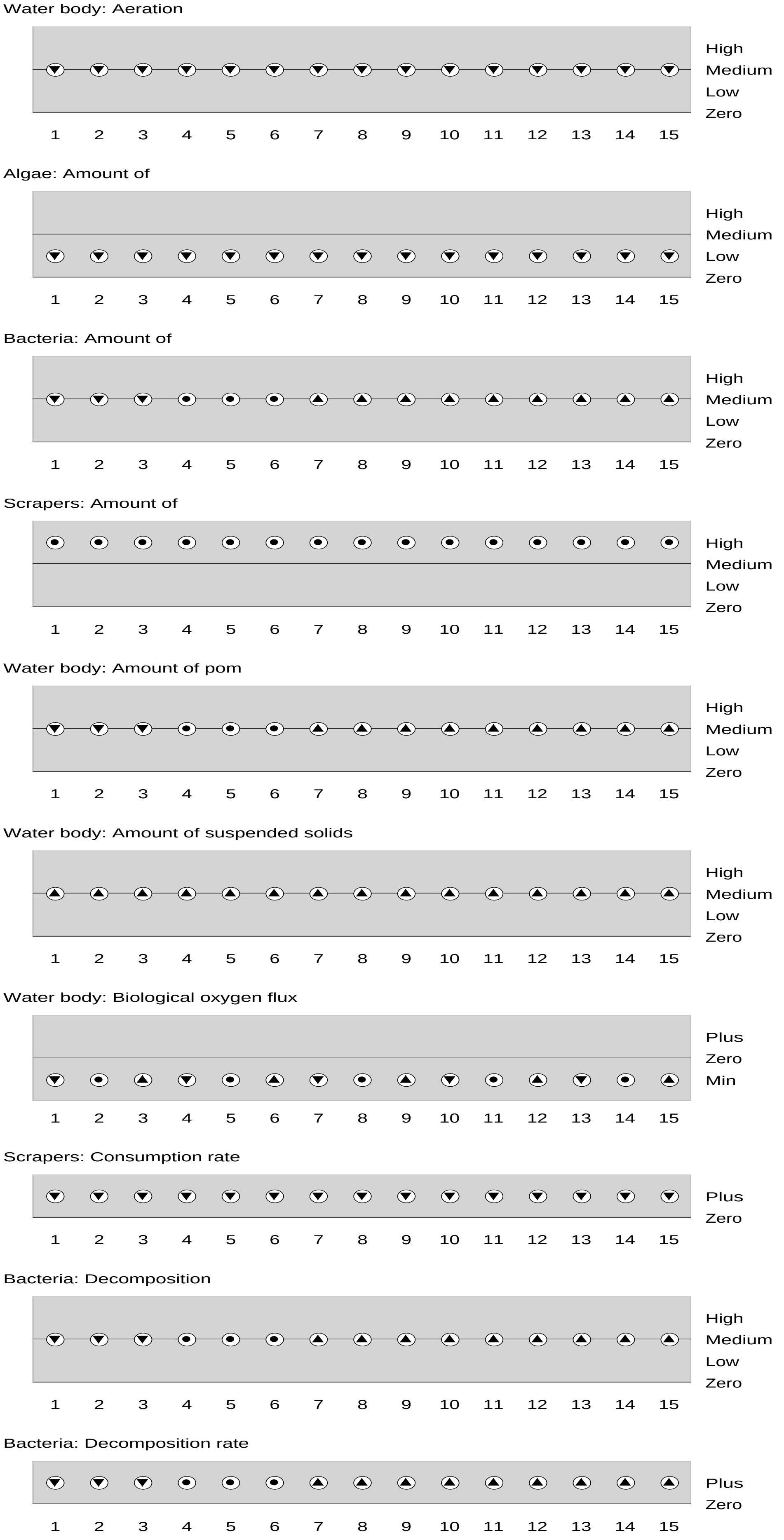
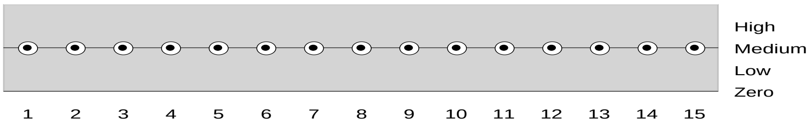



*Figure 67a. Scenario 08 "Pollution, erosion and water abstraction"-Simulation*

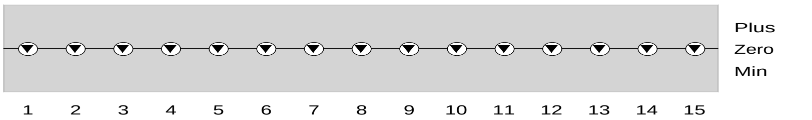
*Figure 67b. Scenario 08 “Pollution, erosion and water abstraction”-Value history*



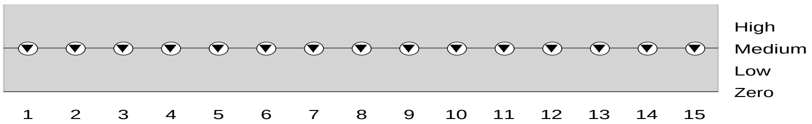
Water body: Diffusion



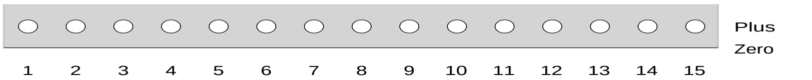

Water body: Diffusion rate



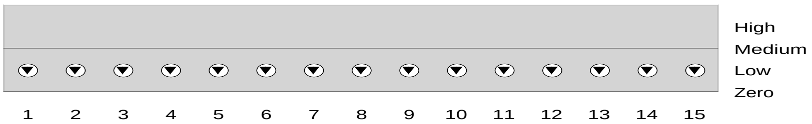

Water body: Dissolved oxygen



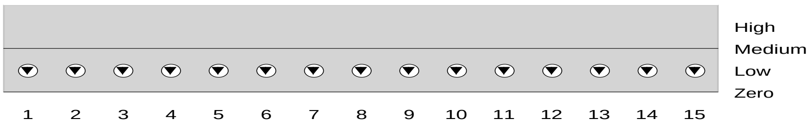

Erosion: Erosion active agent



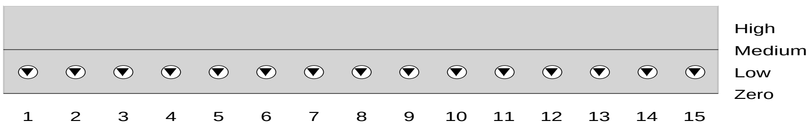

Scrapers: Grazing



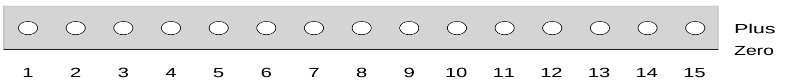

Water body: Light



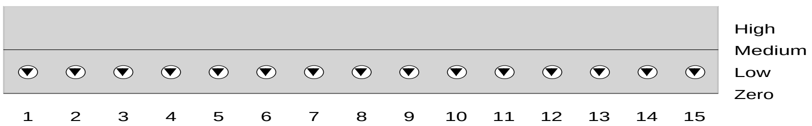

Algae: Photosynthesis



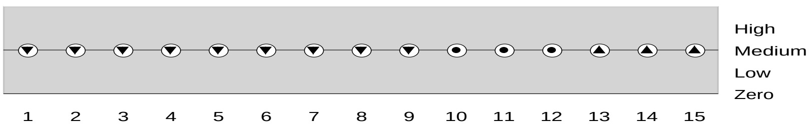

Pollution: Pollution active agent



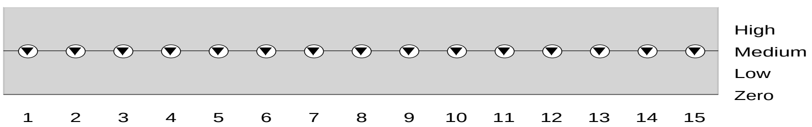

Algae: Respiration



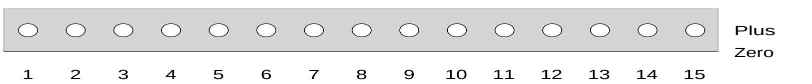

Bacteria: Respiration




Scrapers: Respiration




Water abstraction: Water abstraction active agent



| | |
|---|---|
| Scenario name | Sc 08 Pollution , erosion and water abstraction |
| Full simulation | 15 states |
| Initial states | [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15] |
| End states | No end states |
| Relevant behavior path | No path |
| Behavior description | Simulation has 15 initial states and no end states. In all state Amount of DO is medium and decreasing. |

## *5.3 Causal model and dependency diagrams*

This section shows the different relations between quantities – causal model

### 5.3.1 Scenarios and dependencies concerning physical part of the system (Fig 68)

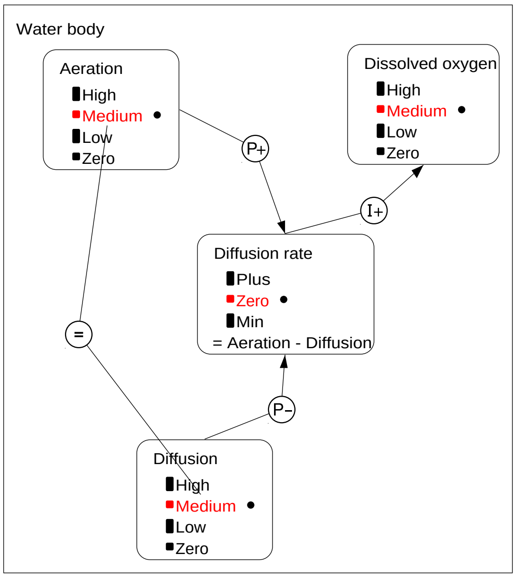



*Figure 68. Causal dependencies Scenario 01 "Physical part of the system oxygen saturation"*

### 5.3.2 Scenarios and dependencies concerning whole River Mesta system ( Fig 69)

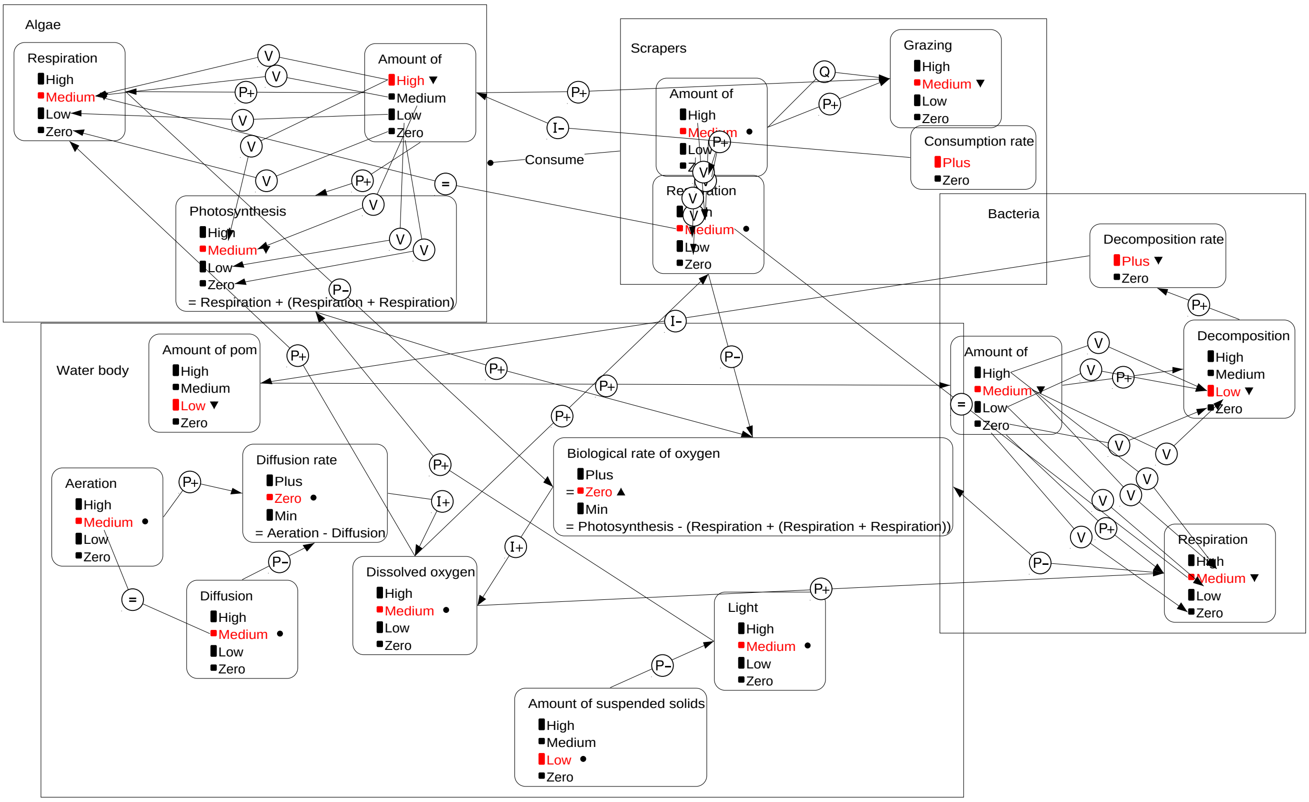


*Figure 69. Causal dependencies Scenario 03 “River Mesta oxygen behaviour”-state3*

### 5.3.3 Scenarios and dependencies concerning agents

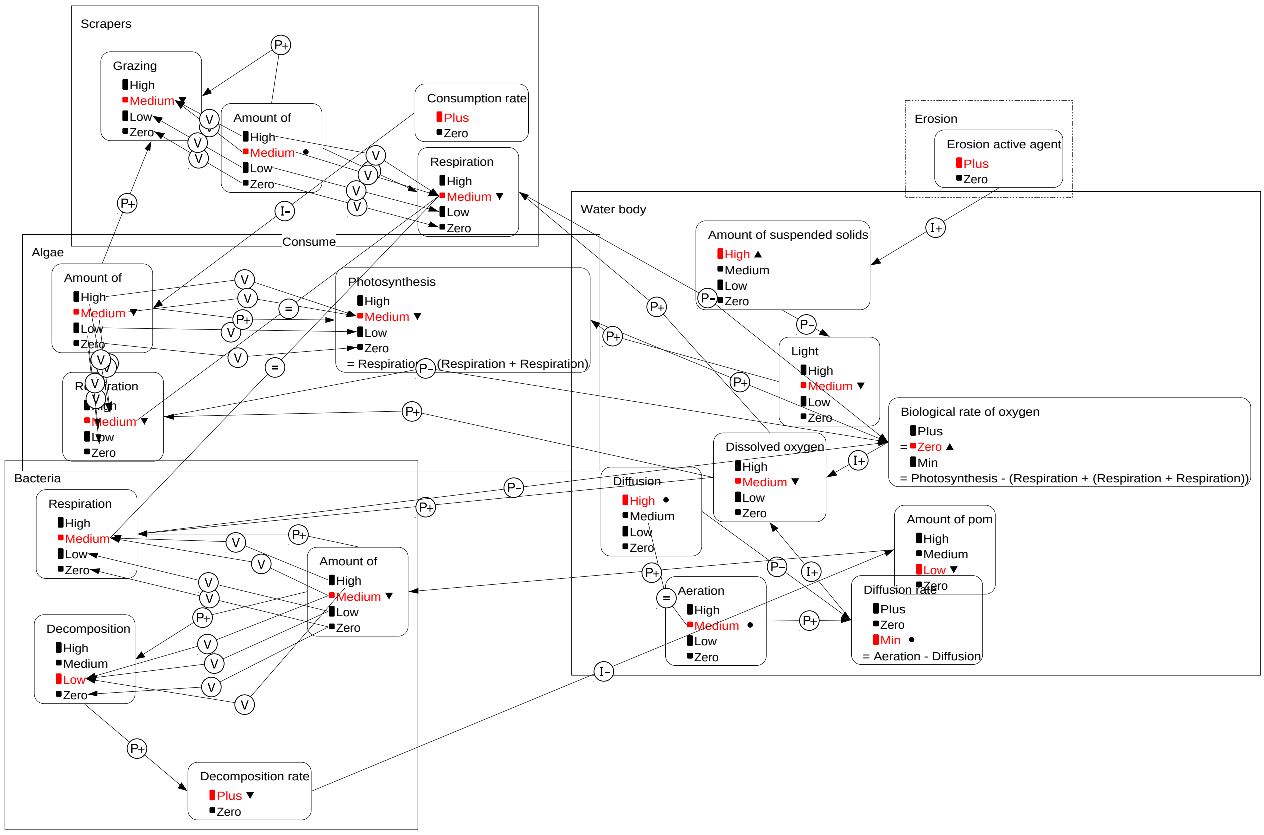



*Figure 70. Causal dependencies Scenario 05 “Erosion”-state3*

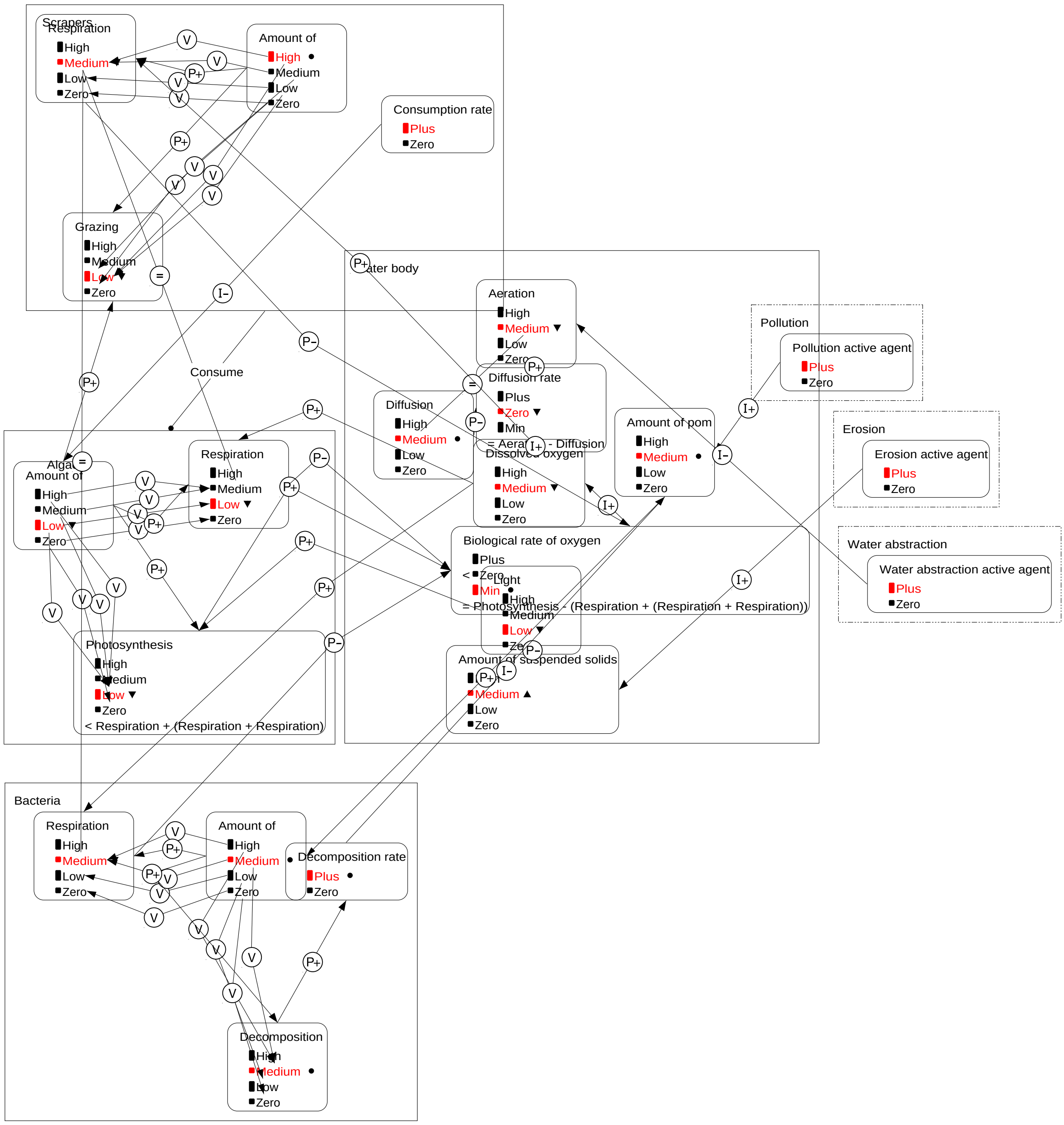



*Figure 71. Causal dependencies Scenario 09 “Erosion, Pollution, Water abstraction”- state3*

# 6 Conclusion

The simulation model about the River Mesta case study and the associated learning materials presented in this document follow the guidelines defined in the Deliverable D6.3.1 (Uzunov and Nakova, 2006a), and refine the prototype presented in the Milestone M6.4 (Uzunov and Nakova., 2006b).

River Mesta model is a complex QR model that shows behavior of stream ecosystem under influence of different processes – biological, physical and chemical. Uncontrolled human activities in watershed can disturb stream ecosystem.

In River Mesta QR model we show the influence of tree external agents – erosion, pollution and water abstraction. These tree agents can change the equilibrium in stream ecosystem, causing decreasing of Amount of DO.

Complete QR model can be used by stakeholders, as a learning material about sustainable development.

***Literature***

1. Bert Bredeweg, Paulo Salles, Anders Bouwer and Jochem Liem (2005) - D6.1 “Framework for conceptual QR description of case studies (www.naturnet.org).
2. Bert Bredeweg, Jochem Liem, Anders Bouwer and Paulo Salles( 2006)D6.9.1 Curriculum for learning about QR modelling (www.naturnet.org).
3. Bert Bredeweg, Anders Bouwer, and Jochem Liem - M6.11 A set of model examples (www.naturnet.org).
4. Forbus, K.D. (1984) Qualitative process theory. *Artificial Intelligence*, volume 24, number 1-3, pages 85-168.
5. Uzunov Y., Nakova E., ( 2006a) “D. 6.3.1 Textual description of River Mesta case study” ( www.naturnet.org).
6. Uzunov Y., Nakova E., ( 2006b) First prototype of a running simulation model of River Mesta case study. Milestone M6.4, NaturNet-Redime, EU STREP, project number 004074.