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Multi-Agent prototype for simulating scenarios for decision-making in river basin systems

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Abstract: Environmental systems are usually extremely difficult to be undertaken by traditional software systems. This is due to the complexity of the environmental domain. Particularly, river catchment systems are very intricate to manage in order to achieve a good quality and quantity of water at the river.

Multi-Agent systems (MAS) are able to cope with this complexity by integrating all the water systems involved at catchment scale through several agents who model real environmental situations.

This work presents the development of our MAS prototype made in the agent platform Jadex. The design was made using the methodology Prometheus. The aim of our prototype is to provide feasible solutions at catchment scale throughout modelling and simulation of different scenarios in a river basin system.

Keywords: Multi-Agent Systems, Decision Support, River basin management

1. Introduction

The complexity of environmental problems makes the management of environmental systems especially difficult to be undertaken by traditional software systems. Particularly river catchment systems are very intricate to manage in order to achieve a good quality and quantity of water at the river.

River catchments are important social, economical and environmental units. They sustain ecosystems, which are the main source of water for households, agriculture and industry. Therefore the protection of all surface waters and groundwaters must be assured in their quality and quantity. The best way to fulfill these requirements is with a management system at catchment scale that integrates all the water systems involved (sewer system, Waste Water Treatment Plants and River) [Devesa 2006].

Multi-Agent systems (MAS) are able to cope with this complexity by integrating several agents who model real environmental situations. This work proposes a design and a prototype development of a River MAS for simulating multiple scenarios in a river catchment system in order to support in the decision-making of river basins management.

The aim of the MAS is to simulate various scenarios in order to draw conclusions and help in the decision-making for the river basin management. There are other objectives to be fulfilled like: to manage critical episodes; to minimize discharge of poorly treated wastewater; to maximize the use of the installations treatment capacity; to minimize the economical costs of new investments and daily management; and to maintain a minimum flow in the river guaranteeing an acceptable ecological state.

The design of the river basin MAS has been made using the Prometheus methodology, taking into account the main elements of the environmental system at catchment scale and representing each element as an agent. The prototype is being developed in the agent platform Jadex.

1.1 River Basin Case Study Description

The Besòs basin is located on the North East of the Mediterranean coast of Spain. The catchment area is one of the most populated catchments in Catalonia, having more than two million people connected. The scope of the study area is around the final reaches of the Congost River. The river sustains, in an area of 70 km², the discharges of four towns which are connected to two Waste Water Treatment Plants (WWTP) [Devesa 2006]. For the development of the MAS prototype two sanitation systems were taken into account (La Garriga and Granollers) with their respective sewage systems and Waste Water Treatment Plants, and one section of the Congost river, an effluent of the Besòs river, as a receptor environment for their waste water.

Hydraulic infrastructures for sanitation have traditionally been managed separately, taking into account only the characteristics of the water at the entry and exit points of each installation. The current tendency is to treat the hydrographic basin as a single area of operations within which hydraulic infrastructures have to be managed in an integrated manner, bearing in mind the condition of the receptor environment.

The water system has three key elements which are depicted in Figure 1: sewer system, WWTP and river. The main elements of the environmental system are listed below.

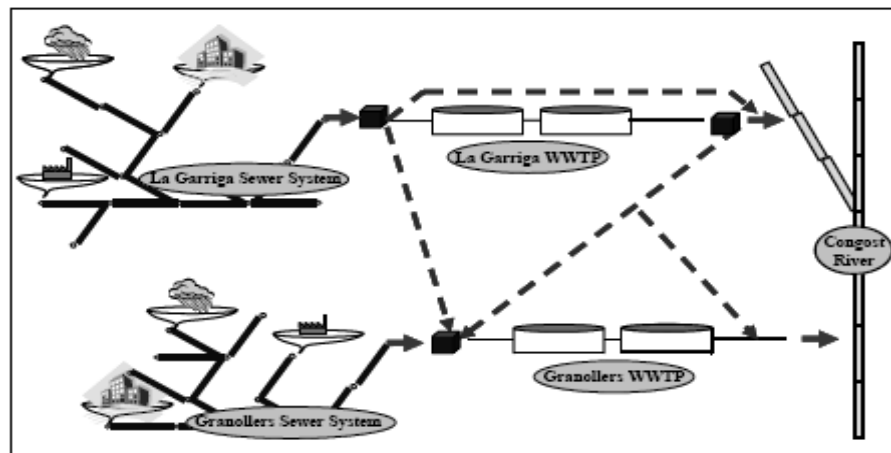


Figure 1. Elements of the environmental system

- *Sewer system.* There are two sewer systems, one that drains the area of the town La Garriga and another one that drains the area of Granollers and some small surrounding villages.
- *WWTP.* There are two WWTPs, one for each sewer system. Both plants have a biological treatment. The average flows are 6000m³/d for La Garriga (WWTP1) and 26000 m³/d for Granollers (WWTP2).
- *River.* The studied reach of the Congost River has a length of 17 km. The Congost is a typical Mediterranean river with seasonal flow variations. Before the two WWTP, the

average flow is about 0.5 m³/s, but can easily reach a maximum punctual flow of 200 m³/s.

- *Industry.* There are 24 industries connected to Granollers system and 4 connected to La Garriga. These industries have a very high rate of potential pollution.
- *Sewer channel.* Joins the two WWTPs, allowing to by-pass the flow from the La Garriga-WWTP to the Granollers-WWTP.

Other considered elements are rain control stations, river water quality control stations, flow retention and storage tanks.

The rest of the paper is organised as follows: In Section 2, it is introduced the river basin MAS. Sections 3 and 4 present the design and development respectively of our MAS prototype and Section 5 states the conclusions.

2. River basin MAS

Following are described the type of agents defined for our MAS proposal. The agent's graphic representation and the dependences among them are depicted in Figure 2.

Type of agents:

- *Sewer agents:* La Garriga Sewer system, Granollers Sewer system. These agents are responsible for the management of the sewer systems. They are aware of the rainfall, the runoff produced by industrial discharges or rainfall incidence and the level of the water flow in the sewer systems.
- *WWTP agents:* Data Gathering, Diagnosis, Decision support, Plans and actions, Connectors. They receive information from the sewer system agents and the storage tanks to start working on the water flow. The agents perform various processes like data gathering, diagnosis of the water using a Case-based reasoning system and a Rule based system, formulating an action plan, user-validation of the plan, etc.
- *River agents:* Data gathering (data required: meteorological, physical, kinetic, water quality). They collect valuable data in order to monitor the state of the river.
- *Storage tanks agents:* Industrial parks, Rainfall. There are two types: the industrial parks control the flow from the industrial area and the rain retention can manage the rain flow.
- *Manager agent.* It is responsible for the coordination between all the elements of the system. This agent interacts and supports the user in the decision-making. It starts and terminates all other agents and handles the communication between them.

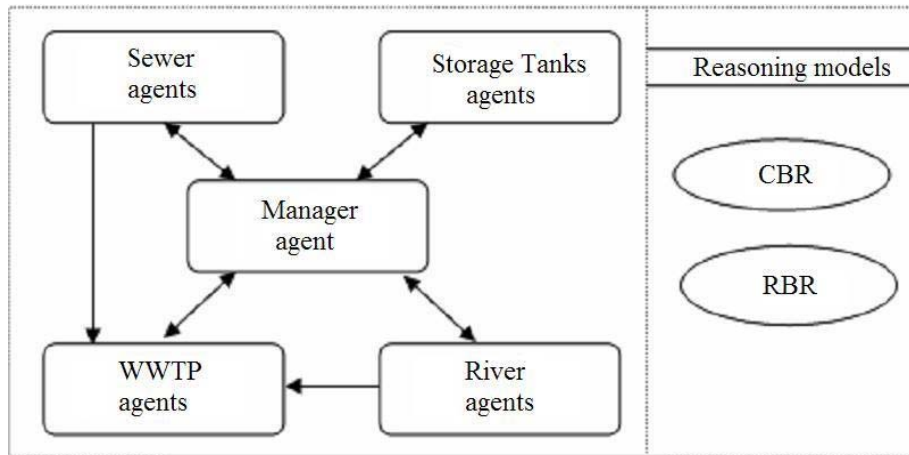


Figure 2. River Basin MAS architecture

2.1 Functionality of the River Basin MAS

The aim of the MAS is to simulate various scenarios in order to draw conclusions and help in the decision-making for the river basin management. The objectives to be achieved are:

- To manage critical episodes
- To minimize discharge of poorly treated wastewater
- To maximize the use of the installations treatment capacity
- To minimize the economical costs of new investments and daily management
- To maintain a minimum flow in the river guaranteeing an acceptable ecological state

In order to accomplish these objectives each intelligent agent will be provided with domain knowledge by means of Case Based Reasoning (CBR) and/or Rule Based Reasoning (RBR) or other reasoning models. Hence they can perform several tasks including:

- By-passing the water flow from La Garriga WWTP to Granollers WWTP.
- Storage tanks management
- Sewer system control
- Monitoring the river basin system

Agent architecture

Among the numerous deliberative agent architectures found nowadays the most widespread one is the Belief-Desire-Intention (BDI) introduced by Bratman as a model for describing rational agents [Bratman 1987]. The BDI architecture uses the concepts of belief, desire and intention as mental attitudes. Beliefs capture informational attitudes, desires motivational attitudes, and intentions deliberative attitudes of agents [Rao and Georgeff 1995].

Both Prometheus and Jadex support the BDI architecture. Therefore, we have represented the agents with their beliefs (meaning the environment knowledge of the world), their goals representing the objectives they are trying to achieve and the plans that are the agent's means for accomplishing its goals.

3. Design in Prometheus

The following section describes the MAS design made in Prometheus [Padgham and Winikoff 2004]. In the *system specification* phase we modelled the environment by identifying the incoming information through percepts and determined the actions that the agents perform. Additionally the system goals and the basic roles of the system were identified. Figure 3 depicts the roles defined for our MAS. It shows the roles needed to achieve the system goals. Roles are depicted by rectangles, goals with ovals and actions with an action icon. An example of a Role descriptor is characterized in Table 1 for the Role Storage tank management.

Table 1. Role descriptor for Storage tank management.

Storage tank management –descriptor	
Name	Storage tank management
Description	1)It retains water during rain peak times and discharges it during low peaks. 2)Laminates waste waterflow. 3)Mitigates pollution episodes due to punctual discharges to the sewer
Percepts	RainfallDetected, StorageTankMeasurement
Actions	WaterDischarge, WaterRetention, LaminateWater
Information used	SCADA
Goals	To manage Critical Episodes, To minimize discharge of poorly treated wastewater

The system overview diagram shown in Figure 3 depicts the five types of agents of our MAS along with their percepts and actions. In addition the major data repositories are described as well as some messages that are sent between agents.

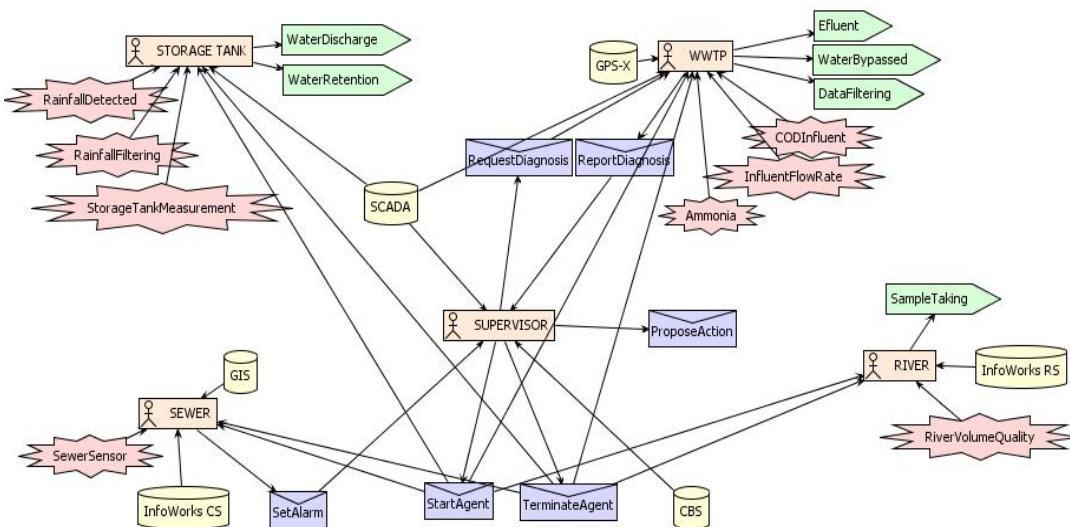


Figure 3. System Overview Diagram

Figure 4 shows the roles defined for the agents. This figure depicts the role attached to the goals it pursues and the percepts and actions of each one.

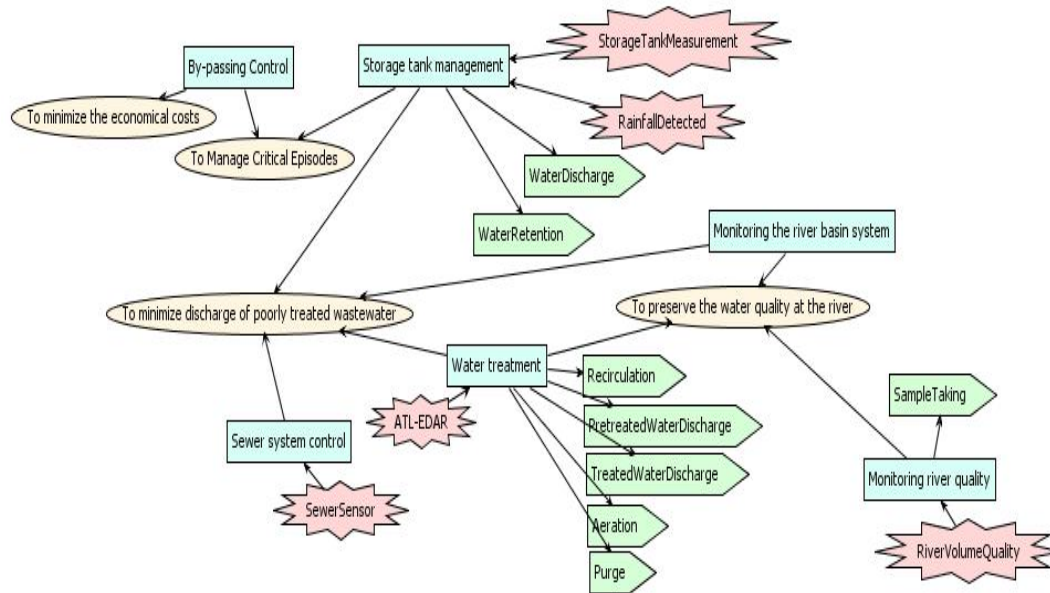


Figure 4. Roles Diagram

4. Implementation of the MAS prototype in Jadex

For the development of a prototype for our case study we selected the agent platform Jadex [Pokahr et al 2006]. The prototype features the main elements of the hydraulic infrastructure as agents and it aims to manage the environmental system as a single area, integrating the two sanitation systems (La Garriga and Granollers) with their respective sewage systems and Waste Water Treatment Plants, as well as the Besòs river as the receptor for their waste water.

Other elements are rain control stations, river water quality control stations, flow retention and storage tanks. There also is a sewer channel that connects both WWTPs, allowing to by-pass the flow from the La Garriga-WWTP to the Granollers-WWTP.

Figure 5 depicts a screenshot of our prototype. It depicts the main elements of the environmental system represented by the agents defined in Section 2.

At this stage we are focusing in the Storage Tanks agents. These agents play an important role in the management of the river basin because they provide crucial advantages that allow preserving the water quality at the river:

- Reduce the overflow (residual water + rain water)
- Laminate the entry flow of the WWTP in dry weather
- Reduce the impact of uncontrolled industrial spills over the WWTP's and river

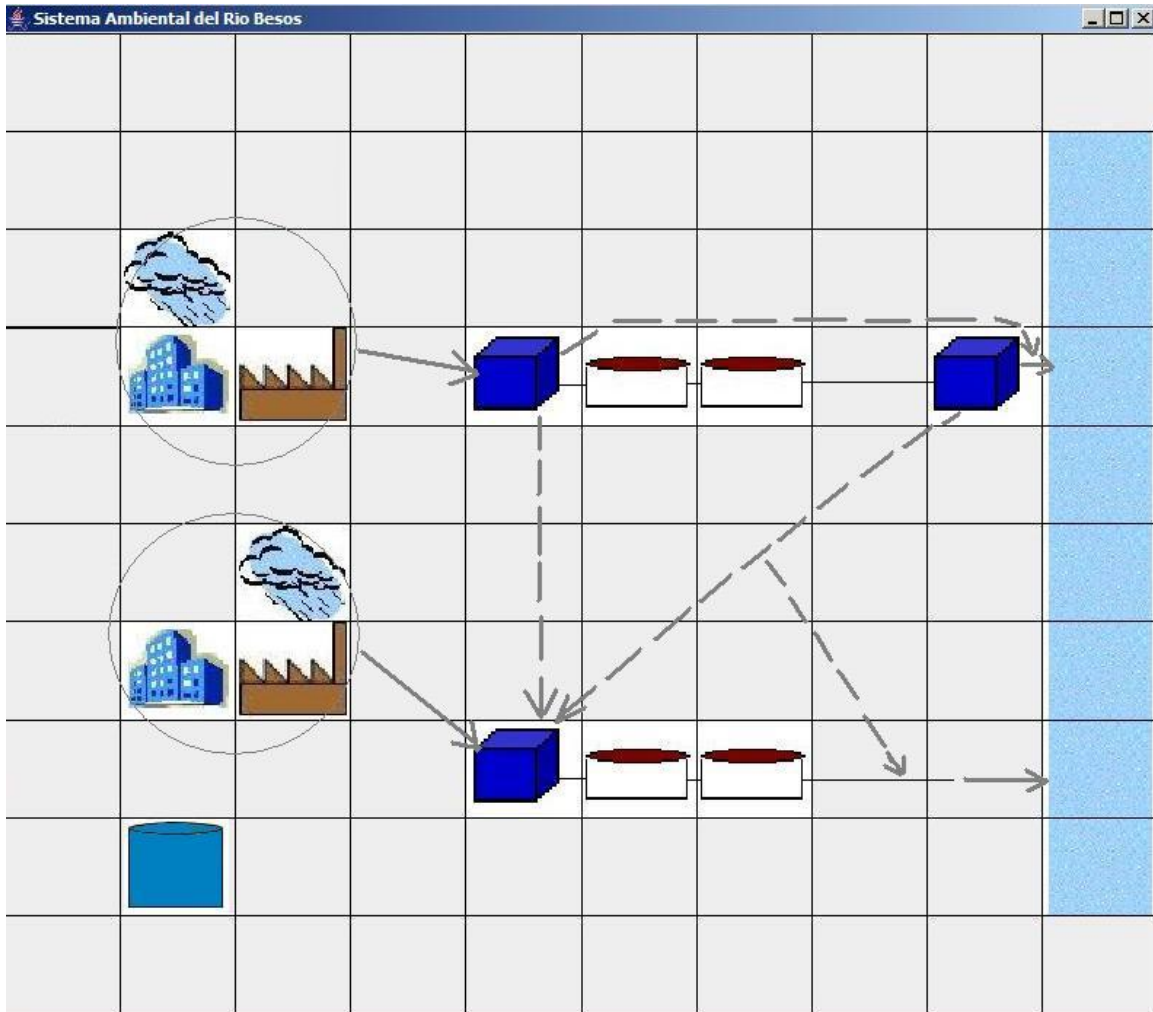


Figure 5. Agents Screenshot in Jadex

In a previous work on the Besos river basin, various scenarios were simulated integrating water quality models in the environmental system [Devesa 2006]. The outcome of these simulations was valuable information about the consequences of some situations over the water quality studied. With this information and the knowledge provided by the experts of the WWTP's a set of actuation rules and tree decisions were defined for dealing with especial situations thus the impact on the water quality of the river is minimal. Based on these trees we extracted the sequence diagrams and the set of actuation rules for creating our beliefbase. In the following subsections we explore in detail the functionality of the decision trees and we explain the sequence diagrams, beliefset and goals.

4.1 Decision Trees

These decision trees were formulated taking into account the knowledge from the experts of the WWTP and the information provided by the simulation of various scenarios [Devesa 2006]. The set of actuation rules represented in the trees aim to minimize the impact on the water quality of the river. Instead of one decision tree, there are three decisions trees for the management of the storage tanks.

- Storage tanks management in dry weather
- Storage tanks management in raining weather
- Storage tanks management in pollution episodes

The storage tanks assumed are located at the sewer networks. Three tanks are at the sewer system La Garriga with a total capacity of 7000m³ and four tanks are at Granollers sewer system with a total capacity of 33000 m³.

Storage tanks management in dry weather

The objective of this decision tree is to laminate the incoming flow at the WWTPs. The tanks hold the water at rush hours and discharge it at regular hours.

Figure x depicts the decision tree for dry weather. The first premise to be fulfilled is that the pluviometers do not sense rain. In this case the tree for raining weather is activated instead. If the pluviometers are not activated the next step is to check the water level at the storage tanks. If the level is larger than 50% of the maximum level then the discharge control is activated. In the opposite situation the dry weather tree holds thus it can laminate the flow. This guarantees that the storage tanks have enough space for holding runoff water when raining.

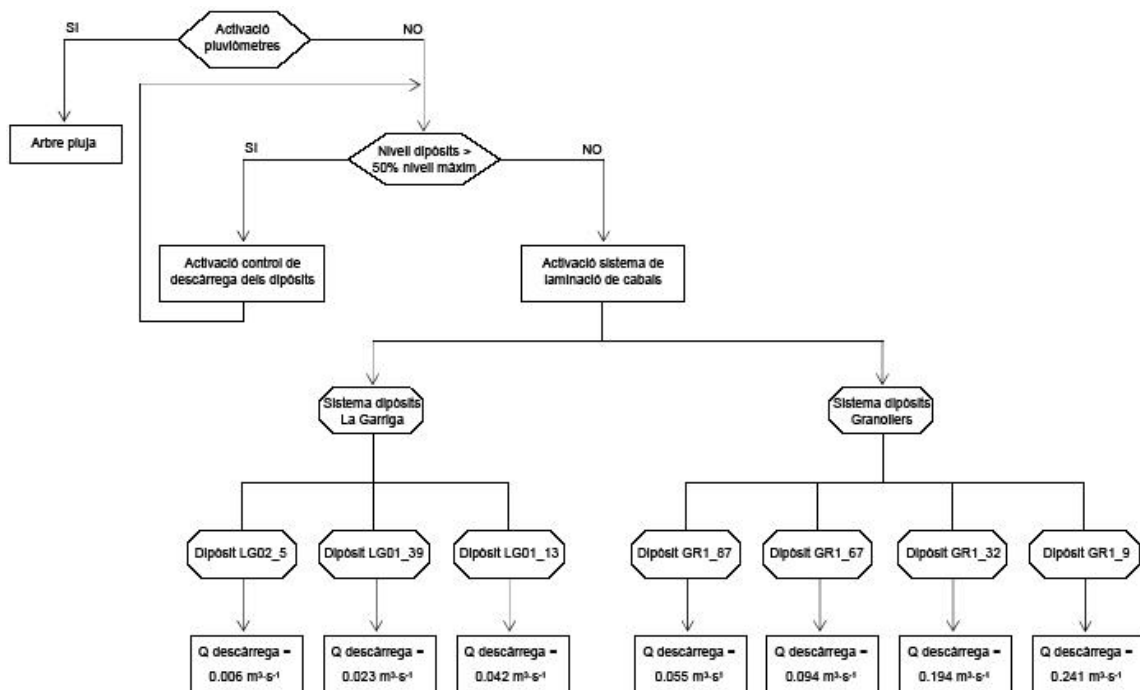


Figure 6. Tree for dry weather

Storage tanks management in raining weather

The objective of this decision tree is to regulate the discharge flow of the storage tanks facing a raining situation. When there is a raining episode, the sewer systems gather part of the precipitated water. In the very first moments of this episode the runoff produced drags the pollution accumulated in the surface and the sewer network. If the rain intensity is too high the sewer network fails to absorb all the water causing the actuation of the overflow and the following spill of this water directly to the river. The storage tanks retain the initial peak of rain, preventing the overflow at the most critical time.

In Figure x the decision tree for raining weather is shown. First, the pluviometers must detect rain. If they do not then the dry weather tree is activated. If rain is detected, then the less intense or short rains are discarded. The pluviometers send rain signals every 5 minutes. In order for this decision tree to hold one of the following premises must be fulfilled:

- The signals in a row sent by the pluviometer is ≥ 3
- The signals sent in an hour ≥ 4
- One single signal $\geq 2\text{mm}$

If one premise is fulfilled the discharge control is activated. The discharge flow is determined according to the water level in each deposit.

Storage tanks management in pollution episodes

The objective is to laminate the extraordinary pollution episodes that happen at the sewer network. In the study area, especially at Granollers, the industrial activity is very intense.

This fact increases the risk of accidental spills of polluting matters to the sewer network. These spills usually have high concentrations of ammonium. The storage tanks can distribute the flow spilled through time, decreasing the impact over the WWTPs and the river.

First the sewer sensor must send an alarm. In the opposite case the dry weather tree is activated. If the alarm was sent then is it checked if there is significant rain for launching the rain weather tree. If there is no rain the potential of the pollution episode is examined by checking the ammonium concentration. Ammonium is checked because it is the matter that affects the most the performance of the WWTPs and the water quality at the river.

In order to the storage tanks to work as retaining spills systems, one of the following premises should be accomplished:

Sewer network La Garriga

Concentration of $\text{NH}_4 > 60 \text{ gm}^{-3}$ during 2 hours

Concentration of $\text{NH}_4 > 90 \text{ gm}^{-3}$

Sewer network Granollers

Concentration of $\text{NH}_4 > 75 \text{ gm}^{-3}$ during 2 hours

Concentration of $\text{NH}_4 > 100 \text{ gm}^{-3}$

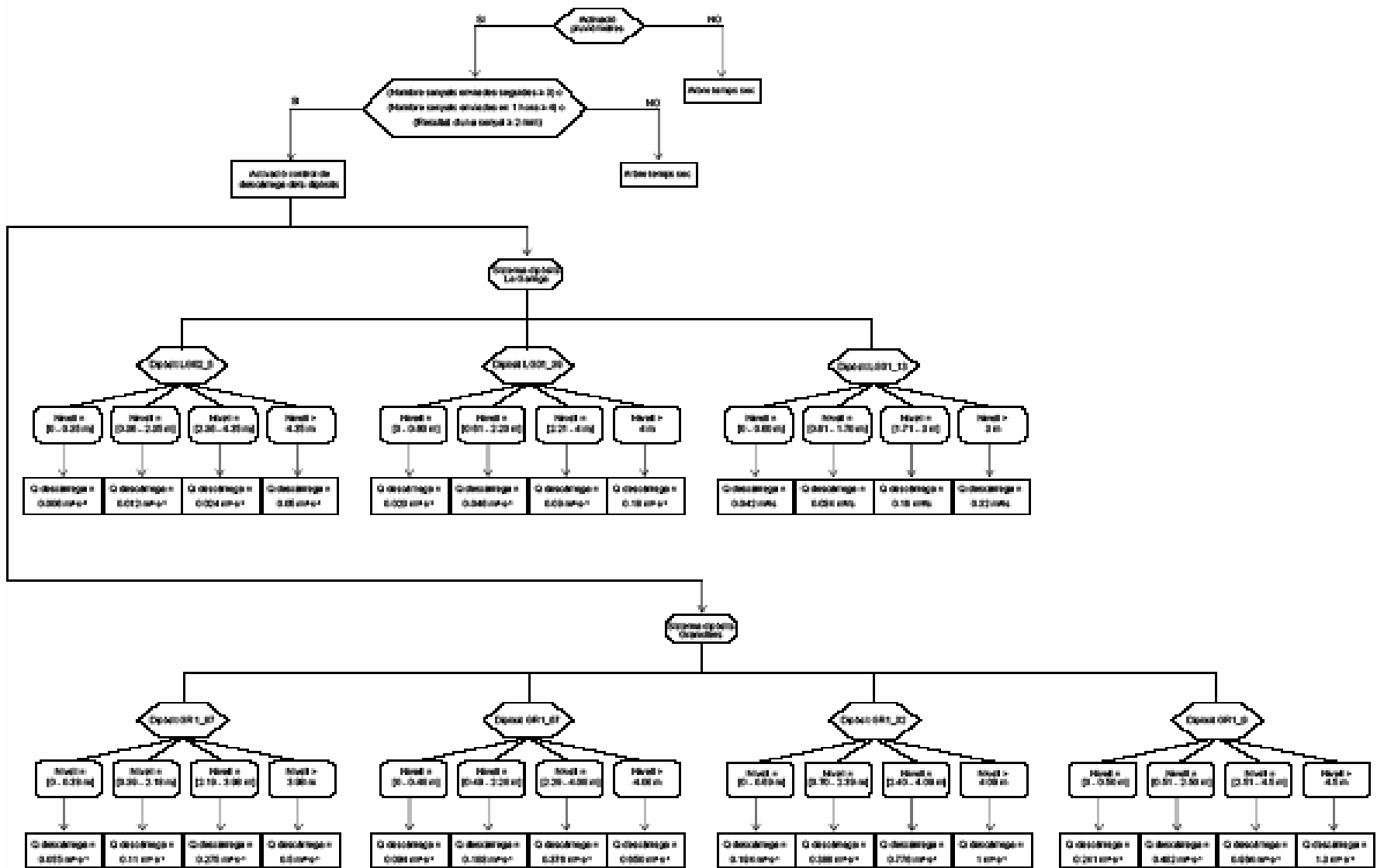


Figure 7. Raining weather tree

If none premise is fulfilled the dry weather tree is activated. When one premise is fulfilled the retaining control of spills is launched. This control assigns the discharge flow to each storage tank. This flow has been decreased 15% for increasing the retaining impact over precise spills. There is also a security restriction for avoiding the overflow at the storage tanks. Meaning if the water level at the tank is over 75% of its maximum level the discharge control of the storage tanks is launched. This tree is activated when the sewer sensors send the alarm signal and, as a security factor, the deactivation is produced two hours after the alarm stops working.

4.2 Sequence Diagrams

Based on the decision trees seen above we have defined the sequence diagrams for the management of the storage tanks. In figures 9, 10 and 11 we can appreciate the sequence of communication between the agents involved in managing and controlling the storage tanks. Thus, these sequence diagrams aid to portray the interaction and dynamic given in the MAS-BDI.

Figure 9 shows the sequence diagram for the dry weather tree and figure 10 shows the sequence diagram for the raining weather tree. These two diagrams are embedded in figure 11 where the sequence diagram for pollution episodes tree is show. Therefore the following explanation of pollution episodes diagram work for the dry and raining weather sequence diagrams.

There are different agents involved, the principal agent is BDI which is the procedural reasoning system, the system it is initialized when it receives the Pluviometer values, Ammonium and a Sewer alarm signals simultaneously, with these values a BDI plan starts. The plan started has to evaluate if the alarm has a critical value and then decide if it sends a start message to the Dry weather tree to initialize the process explained above in the Dry weather tree. If the alarm it is not critical it calls a sub-process to evaluate the pluviometer values, based on this, it sends a message to the Rain weather tree and launches the tree as explained before. If the Pluviometer values are not significant then it checks if the level of Ammonium is high. In that case, it receives the level of Storage tank measurement, if the level is higher than 75% have to call Rain weather tree, otherwise it launches Water Discharge, if the level of Ammonium is lowest then start Dry weather tree.

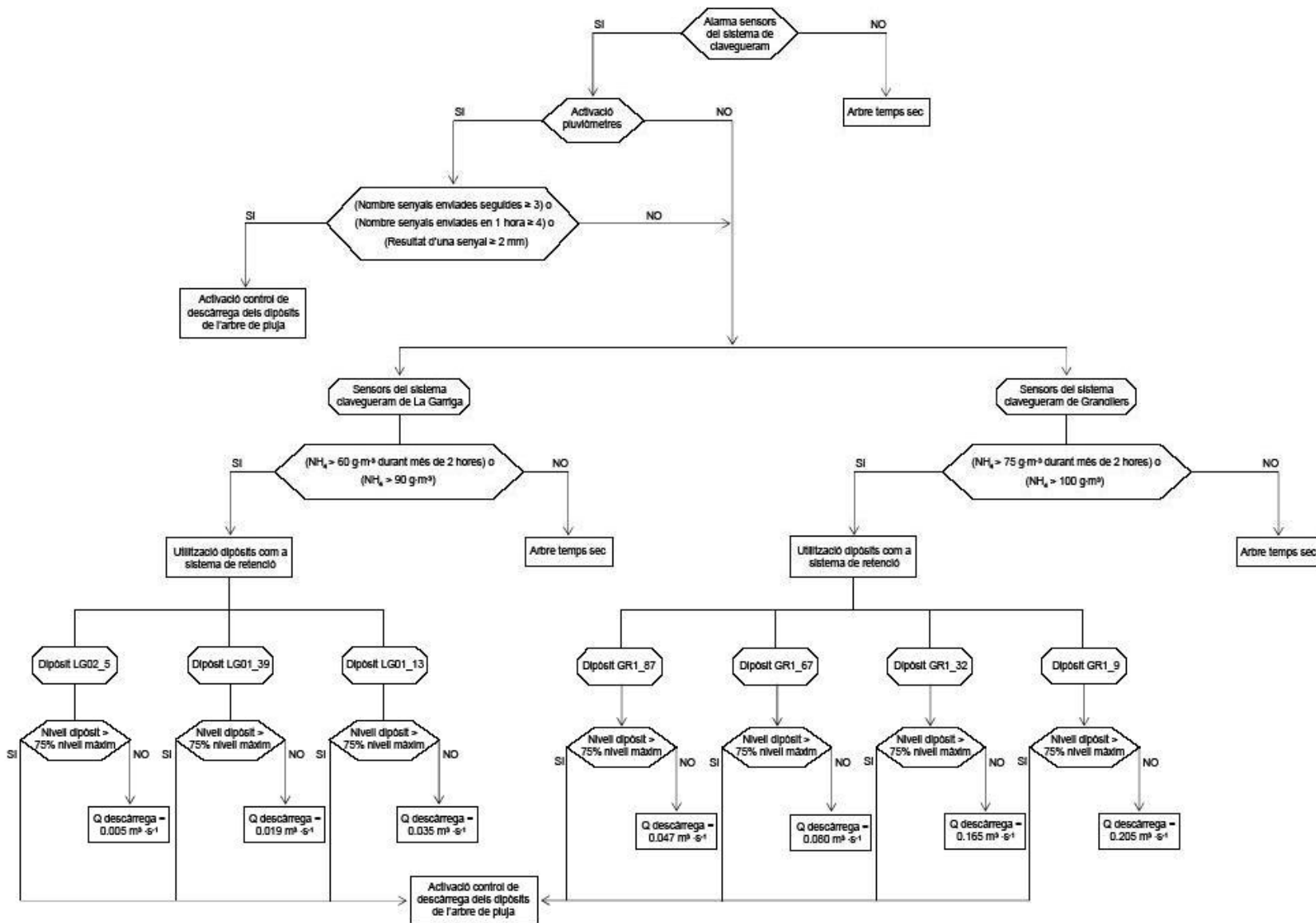


Figure 8. Pollution episodes tree

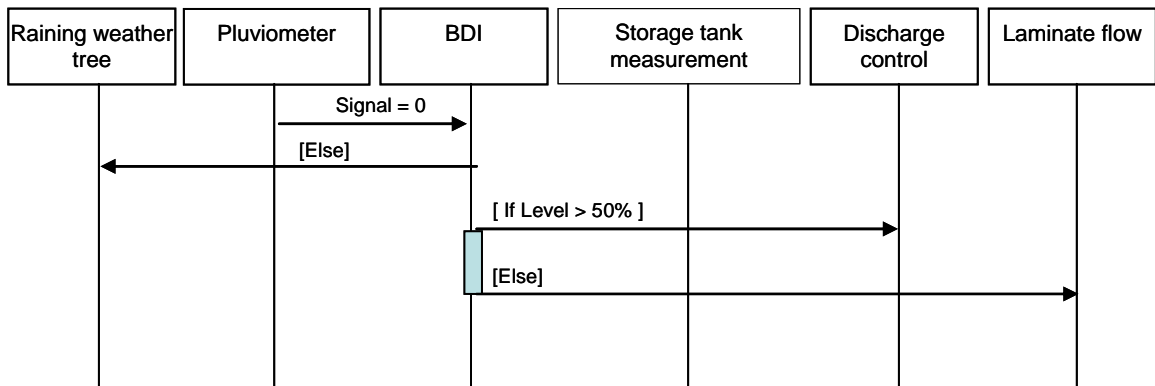


Figure 9. Sequence Diagram for Dry weather tree

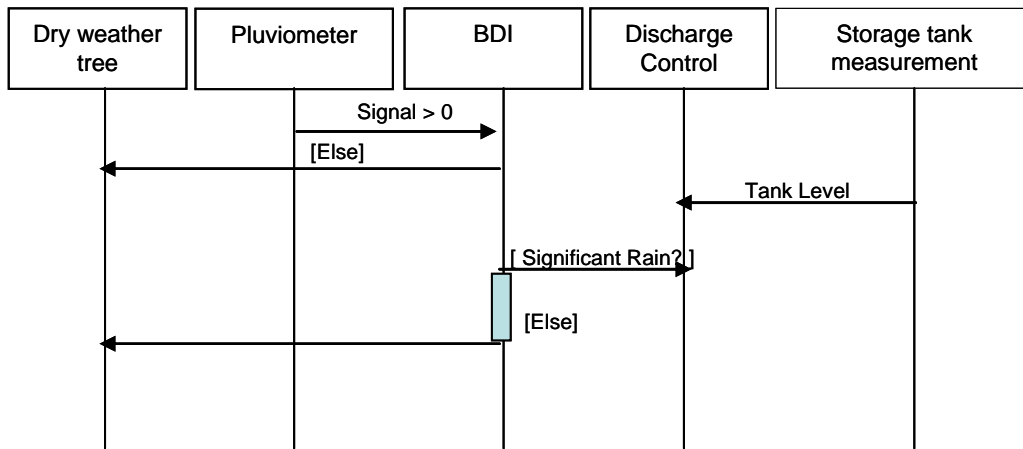


Figure 10. Sequence Diagram for Raining weather tree

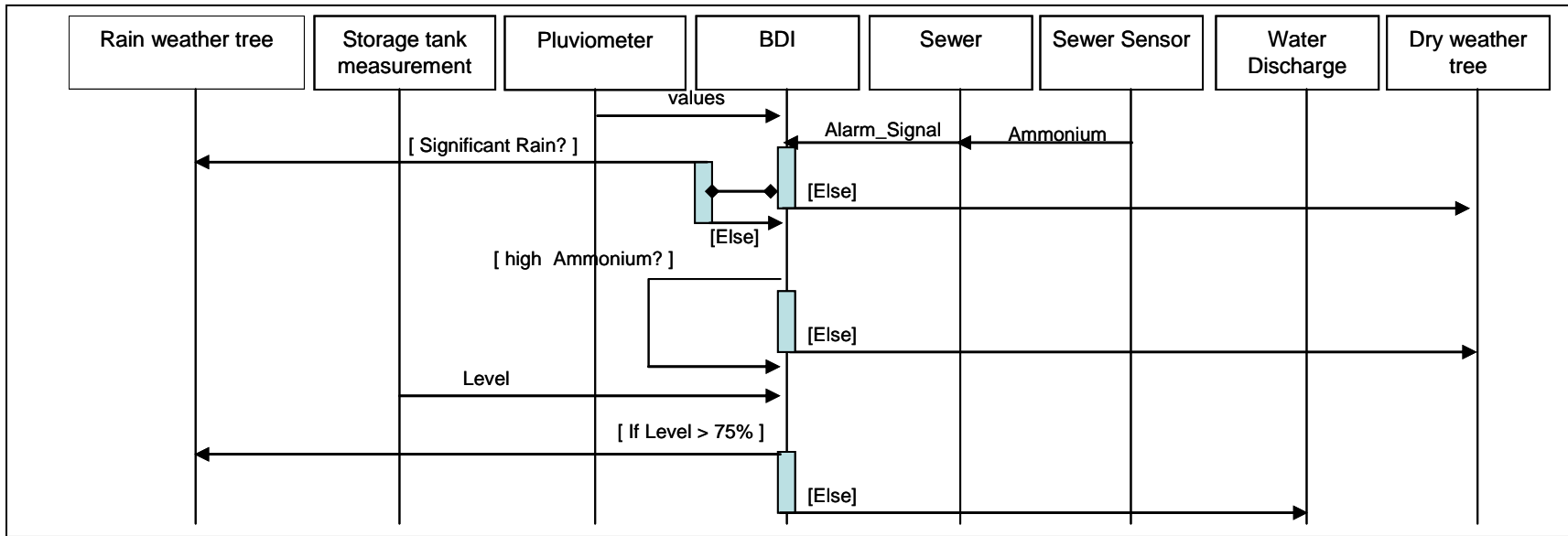


Figure 11. Sequence Diagram for Pollution episodes tree

4.3 Beliefs

Table 2 shows the beliefs extracted from the raining weather tree. This table illustrates the values needed in the discharge control. First column depicts the specific storage tank, next two columns have the minimum and maximum values of the water level for the specific tank, and the last column gives the amount of flow to be discharged (meter per second).

Table 3 and 4 show the values needed for discharge control in pollution weather tree and dry weather tree respectively.

Table 2. Values used for discharge control (Raining weather tree)

STORAGE TANK	MIN. LEVEL	MAX. LEVEL	Q discharge
LGO2_5	0	0.35	0.006
	0.36	2.35	0.012
	2.36	4.35	0.024
	4.35		0.05
LGO1_39	0	0.60	0.023
	0.61	2.20	0.046
	2.21	4	0.09
	4		0.18
LGO1_13	0	0.60	0.042
	0.61	1.70	0.084
	1.71	3	0.16
	3		0.32
GR1_9	0	0.5	0.241
	0.51	2.50	0.482
	2.51	4.5	0.964
	4.5		1.3
GR1_87	0	0.38	0.055
	0.39	2.18	0.11
	2.19	3.98	0.275
	3.98		0.5
GR1_67	0	0.48	0.094
	0.49	2.28	0.188
	2.29	4.08	0.376
	4.08		0.650
GR1_32	0	0.69	0.194
	0.7	2.39	0.388
	2.40	4.09	0.776
	4.09		1

Table 3. Values used for discharge control (Pollution weather tree)

STORAGE TANK	Q discharge
LGO2_5	0.005
LG01_39	0.019
LG01_13	0.035
GR1_87	0.047
GR1_67	0.080
GR1_32	0.165
GR1_9	0.205

Table 4. Values used for discharge control (Dry weather tree)

STORAGE TANK	Q discharge
LGO2_5	0.006
LG01_39	0.023
LG01_13	0.042
GR1_87	0.055
GR1_67	0.094
GR1_32	0.194
GR1_9	0.241

Goals

The following goals were defined in Jadex according to the objectives the agents must achieve. The type of goal was selected based on the purpose of the objective.

Achieve goals:

To manage critical episodes

Perform goals:

To minimize discharge of poorly treated wastewater

To maximize the use of the installations treatment capacity

To minimize the economical costs

Maintain goals:

To maintain a minimum flow in the river

To preserve the water quality at the river

5. Conclusions

The complexity of environmental problems makes the management of environmental systems especially difficult to be undertaken by traditional software systems. Particularly, as mentioned in the introduction, river basin systems are especially intricate to manage in order to obtain a good quality and quantity of water at the river. We have proposed a River Basin MAS to simulate scenarios to support in the decision-making in river basin systems.

Traditionally hydraulic infrastructures for sanitation have been managed separately, taking into account only the characteristics of the water at the entry and exit points of each installation. The current tendency is to treat the hydrographic basin as a single area of operations. We are using this integrated approach in our prototype because it presents more advantages to treat the environmental system as a whole instead of separate units.

The design of the river basin MAS has been made using the Prometheus methodology. We chose Jadex as the agent platform for developing the River Basin MAS. Jadex is a procedural reasoning system and it aids us to integrate CBR and RBR like plans of BDI. At this stage, we are focusing in the Storage Tanks agents because they provide crucial advantages that allow preserving the water quality at the river as explained in Section 4. To integrate knowledge and control the management of the tanks we used the decision trees defined in [Devesa 2006].

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