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Simulation of drinking water infrastructures through artificial intelligence-based modelling for sustainability improvement

Carlos Calatayud Asensi, José Vicente Berná Martínez, Lucia Arnau Muñoz, Vicente Javier Macián Cervera.

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1. Introduction.

In this work we intend to expose a simulation of an intelligent control system (AI) based on Multi-Agent Systems (MAS) that models and exhibits the behavior of a drinking water supply infrastructure.

We have prepared this study based on data obtained from a typical city of 5.000 inhabitants located in the northeast of the province of Alicante.

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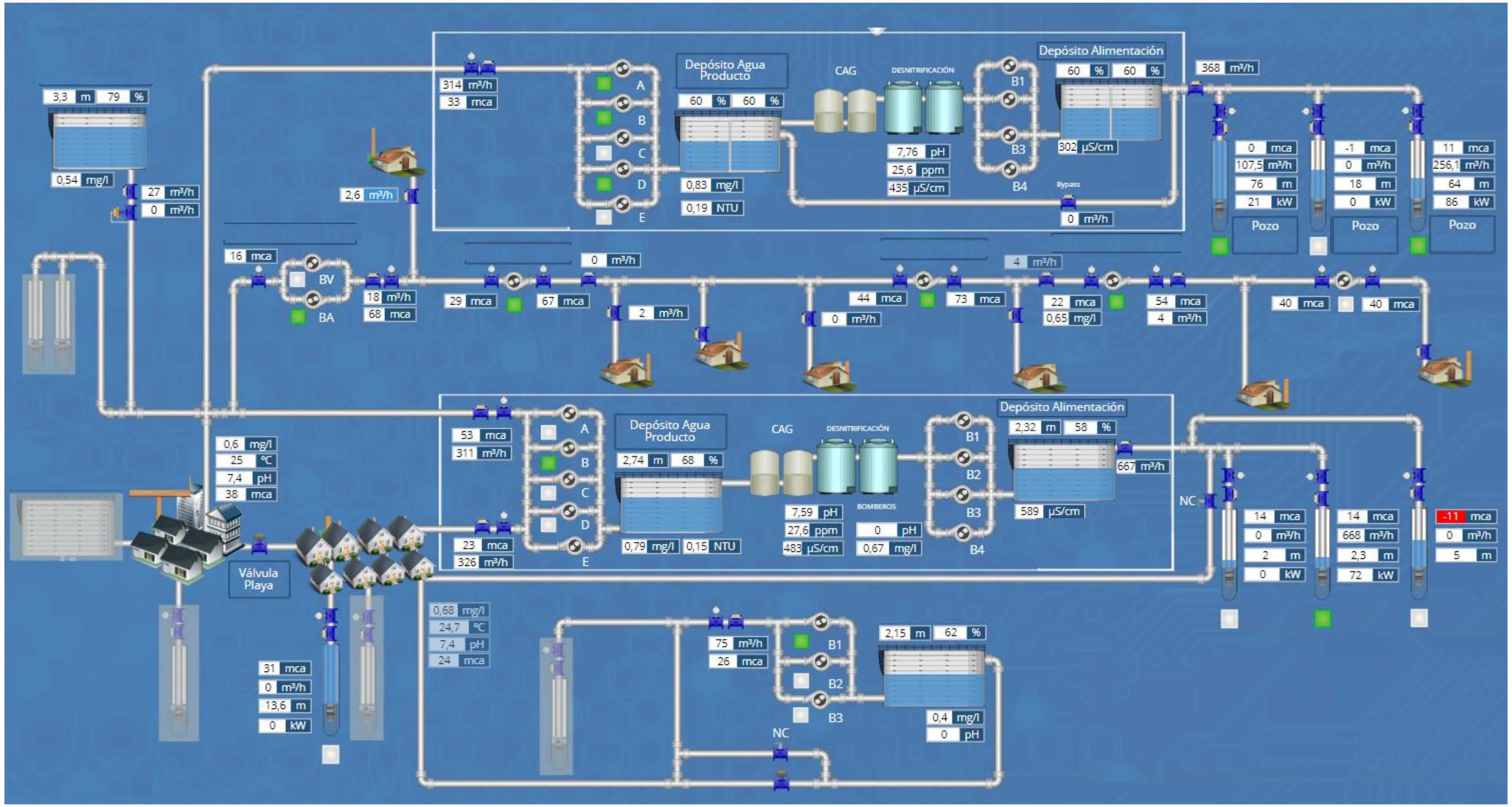
2. Hydraulic systems of drinking water.



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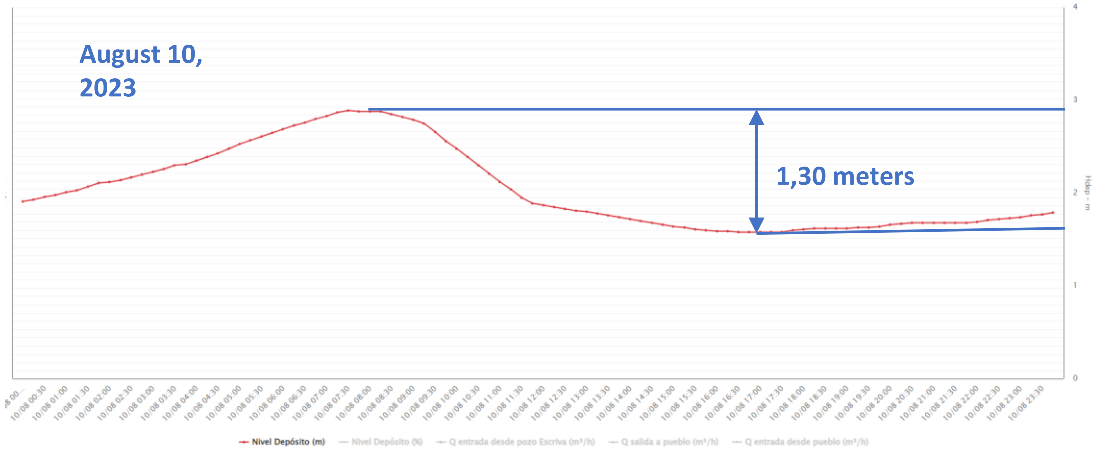
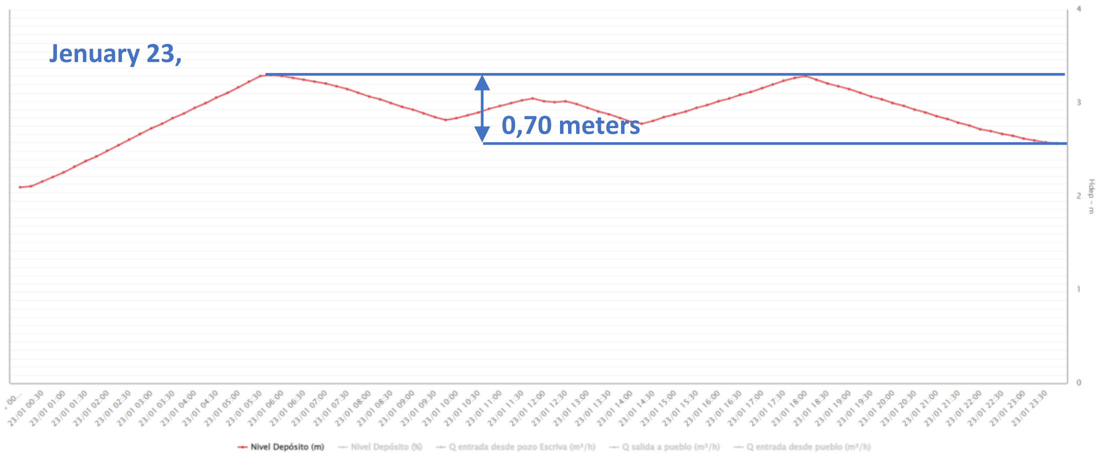
2. Hydraulic systems of drinking water.

And with all of the above, the responsible for the drinking water service have to:

- Guarantee supply to inhabitants.
- Assure the quality of water we supply.
- Reduce the use of chemical products necessary to make water drinkable.
- Reduce energy consumption and direct and indirect greenhouse gases emissions.
- Optimize the use of each of the elements installed in the supply network.

2. Hydraulic systems of drinking water.





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2. Hydraulic systems of drinking water.

At the end, it is almost impossible for anyone to constantly monitor all these variables and act on them in real time.

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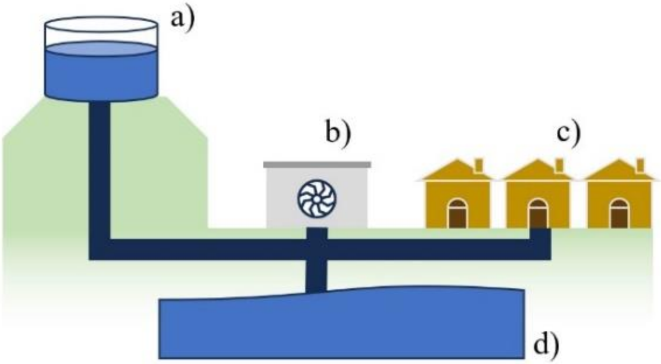
3. Proposed alternative. Starting point.



a) Water tank with bottom inlet
b) Water pumps
c) Urban area
d) Aquifer

- Not consider environmental sustainability. Only consider lower costs pumping.
- Water has been extracted from ground. Aquifers level.
- More uses of chemical products. To preserve running water in optimal condition, we need to dose more sodium hypochlorite.
- In store tanks with inlet at the bottom, we are pressing the rest of the hydraulic system towm and, we need to aplicate more energy to pump the same cubics meters of water.

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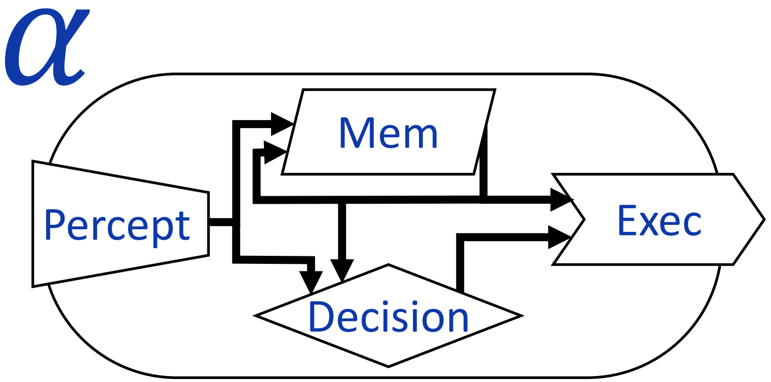
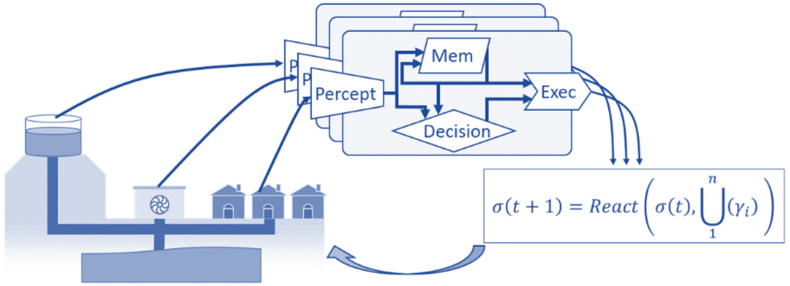
4. Multi-Agent System.





$\alpha = \langle \Phi_\alpha, \Sigma_\alpha, P_\alpha, \Gamma_\alpha, Percept_\alpha, Mem_\alpha, Decision_\alpha, Exec_\alpha \rangle$

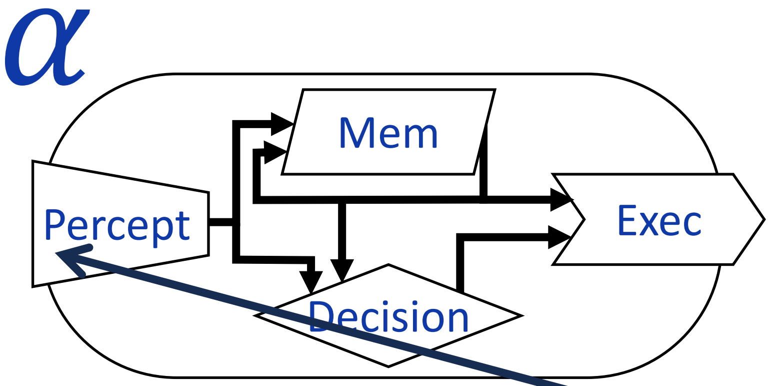
$Percept_\alpha$: $W \rightarrow \Phi_\alpha$ function that generates a perception from the state of the world W.

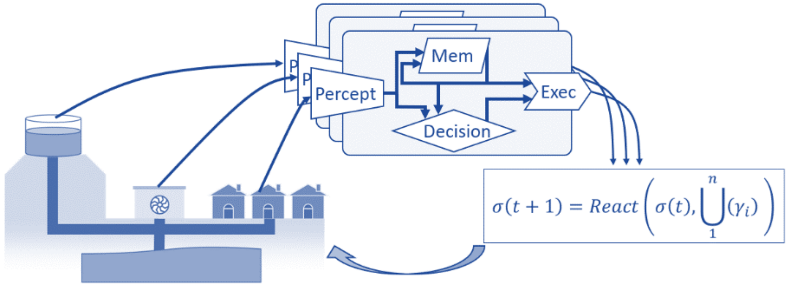
Mem_α: $\Phi_\alpha \rightarrow \Sigma_\alpha$ function that generates a new internal state from the perceived state.

$Decision_\alpha$: $\Phi_\alpha \times \Sigma_\alpha \rightarrow P$ function that generates an action from the perceived and internal state.

$Exec_\alpha$: $P \rightarrow \Gamma$ function that generates an influence from the decided action.

4. Multi-Agent System.





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Mem_α: $\Phi_\alpha \rightarrow \Sigma_\alpha$ function that generates a new internal state from the perceived state.

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Perceives the world, that is, it observes the world and extracts from it the information that interests of its. It has a partial vision of only that which is of interest to it.

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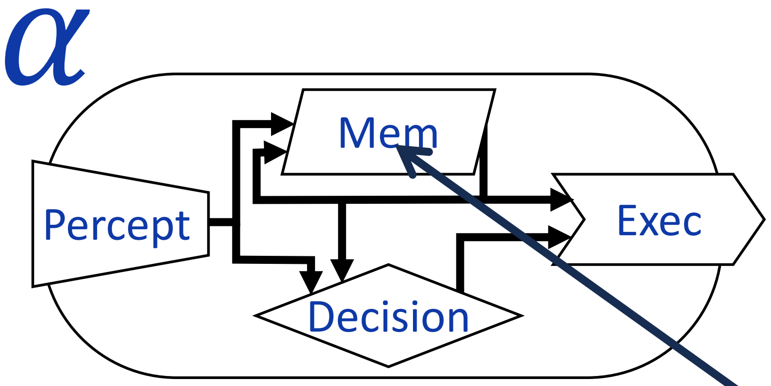

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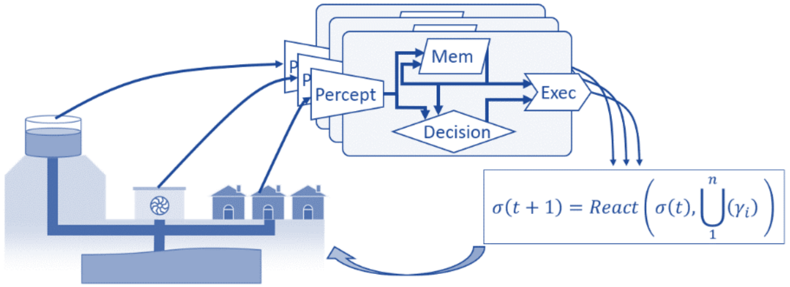

It stores information internally, it has memory, and this memory will or will not store it again depending on our interests.

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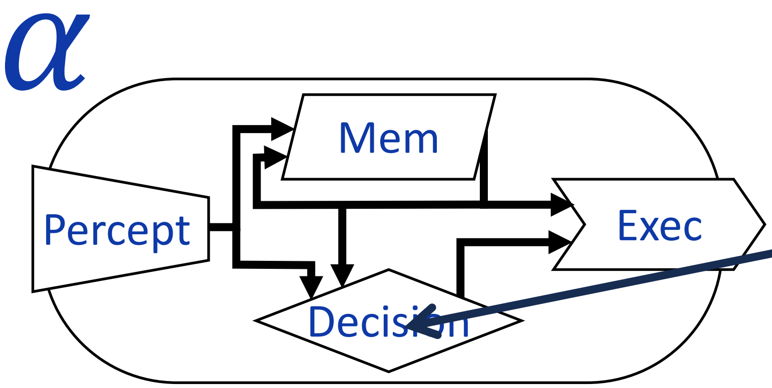
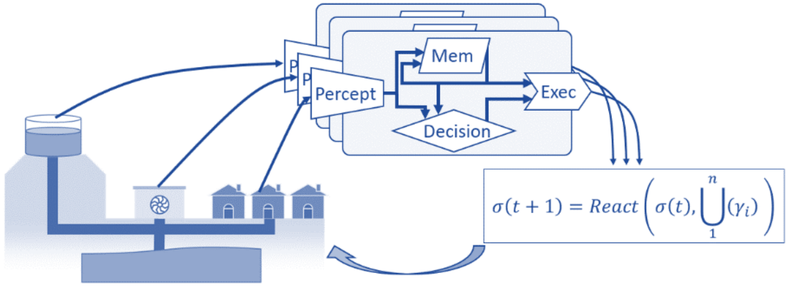
4. Multi-Agent System.





$\alpha = \langle$

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Mem_α: ... m
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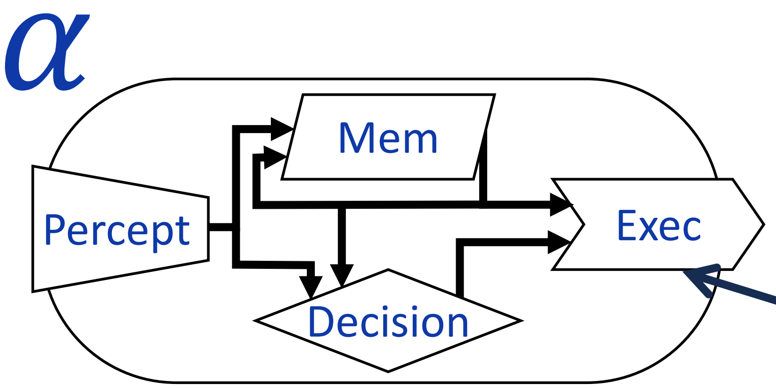
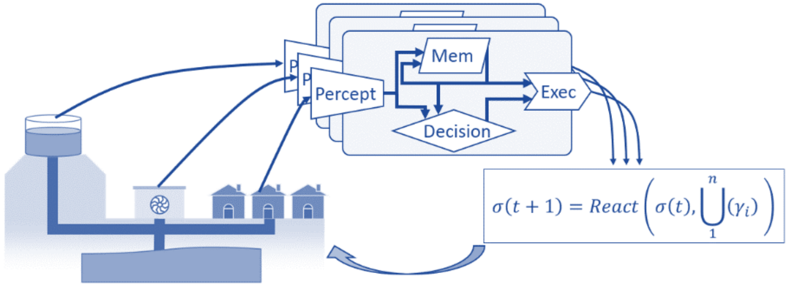
Based on what it perceive and have stored, it makes decisions
And finally releases to the world, executes those decisions

$Decision_\alpha$: $\Phi_\alpha \times \Sigma_\alpha \rightarrow P$ function that generates an action from the perceived and internal state.

$Exec_\alpha$: $P \rightarrow \Gamma$ function that generates an influence from the decided action.

4. Multi-Agent System.





$$\alpha = \langle \Phi_\alpha, \Sigma_\alpha, P_\alpha, \Gamma_\alpha, Percept_\alpha, Mem_\alpha, Decision_\alpha, Exec_\alpha \rangle$$

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Deci … rom
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Finally the execution function attempts to execute each decision, called influences or desires, because the fact, that an agent wants to do something not mean that it will do it totally.

The sum of all influences will be the final execution.

$Exec_\alpha$: $P \rightarrow \Gamma$ function that generates an influence from the decided action.

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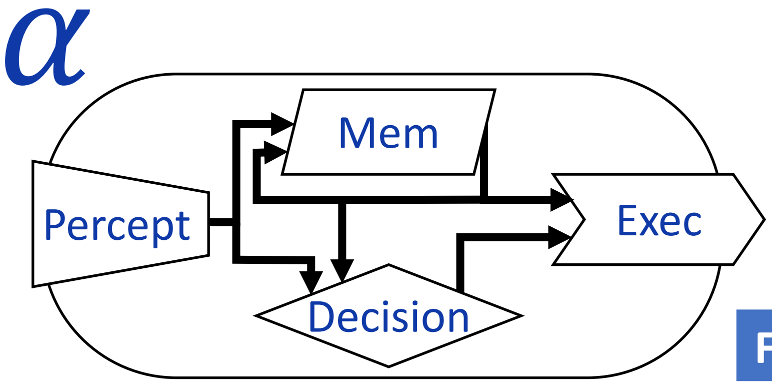
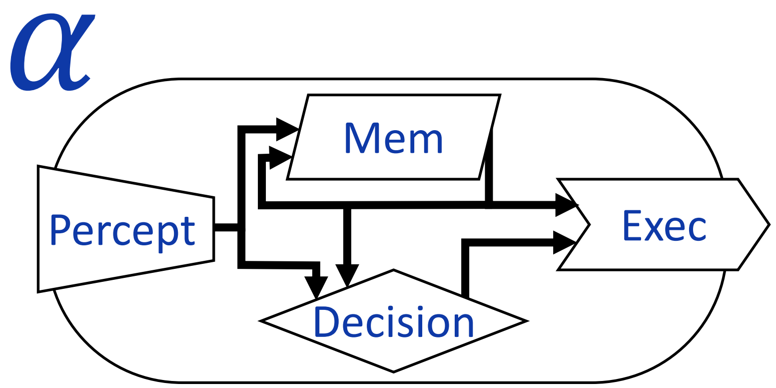


$$\alpha = \langle \Phi_\alpha, \Sigma_\alpha, P_\alpha, \Gamma_\alpha, Percept_\alpha, Mem_\alpha, Decision_\alpha, Exec_\alpha \rangle$$

Func	Element	Description
Percetp	watchList	List of signs to watch
Mem	μ	Attention threshold
Decision	PreD	Decision precondition, triggers an action, can be TRUE
	FunD	Action carried out by the center (signal modification)
Exec	PostE	Generation of influence from action
	PreE	Condition to trigger the influence, can always be TRUE

4. Multi-Agent System.



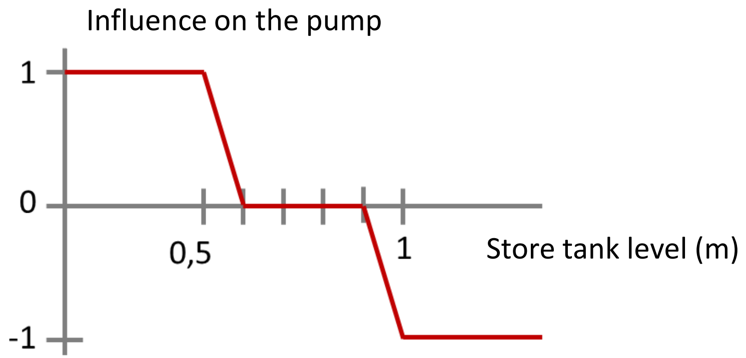
$$\alpha = \langle \Phi_\alpha, \Sigma_\alpha, P_\alpha, \Gamma_\alpha, Percept_\alpha, Mem_\alpha, Decision_\alpha, Exec_\alpha \rangle$$

- Intention 1. Minimize the **level of stored water**, determining the **lower limit 0.5m** and the **maximum limit 1m**. It is necessary to maintain this minimum of 0.5 to avoid carrying sediment from the tank.
- Intention 2. **Avoid pumping** water during periods of maximum consumption in the city, thus avoiding the work of the pumping stations against inertia.
- Intention 3. **Maintain the pressure** of the infrastructure around a reasonable value, avoiding overpressure or low pressure.

4. Multi-Agent System.

- Intention 1. Minimize the **level of stored water**, determining the **lower limit 0.5m** and the **maximum limit 1m**. It is necessary to maintain this minimum of 0.5 to avoid carrying sediment from the tank.

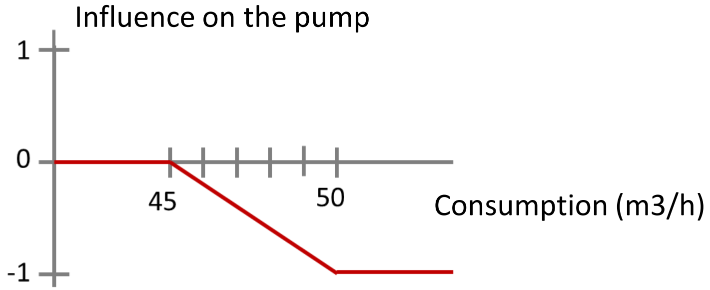
Element	Value
watchList	WaterLevel
μ	0,01 m
FunD	D_l =1 si WaterLevel<0,5 D_l =(0,6-WaterLevel)*10 si 0,5≤WaterLevel≤0,6 D_l =0 si 0,6<WaterLevel<0,9 D_l =(0,9-WaterLevel)*10 si 0,9≤WaterLevel≤1 D_l =-1 si WaterLevel>1
PostE	D_l



4. Multi-Agent System.

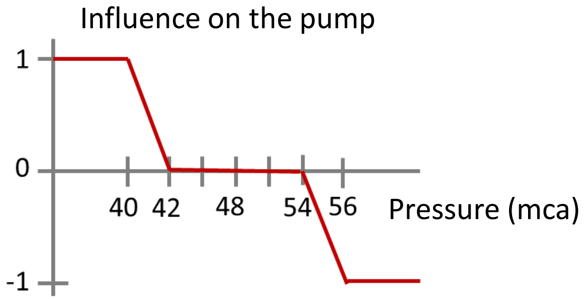
Intention 2. **Avoid pumping** water during periods of maximum consumption in the city, thus avoiding the work of the pumping stations against inertia.

Element	Values	
watchList	consumoAgua → aguaDesdeDeposito, aguaDesdeBomba, aguaHaciaDeposito	
μ	0,5 m^2/h	
FunD	D_i =0 D_i =-(consumoAgua – 45)/5 D_i =-1	si consumoAgua<45 si 45≤consumoAgua≤50 si consumoAgua>50
PostE	D_i	



Intention 3. **Maintain the pressure** of the infrastructure around a reasonable value, avoiding overpressure or low pressure.

Element	Values	
watchList	presionAgua	
μ	0,1 mca	
FunD	D_p =1 D_p =1-(presionAgua-40)/2 D_p = 0 D_p =-(presionAgua-54)/2 D_p =-1	si presionAgua<40 si 40≤presionAgua<42 si 42≤presionAgua≤54 si 54<presionAgua≤56 si presionAgua>6
PostE	D_p	



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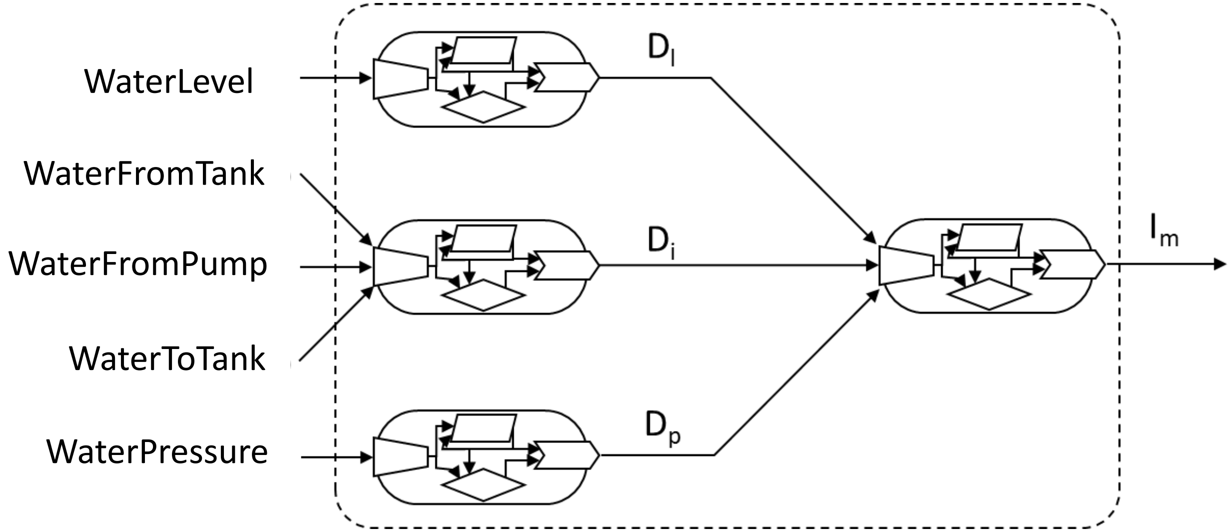
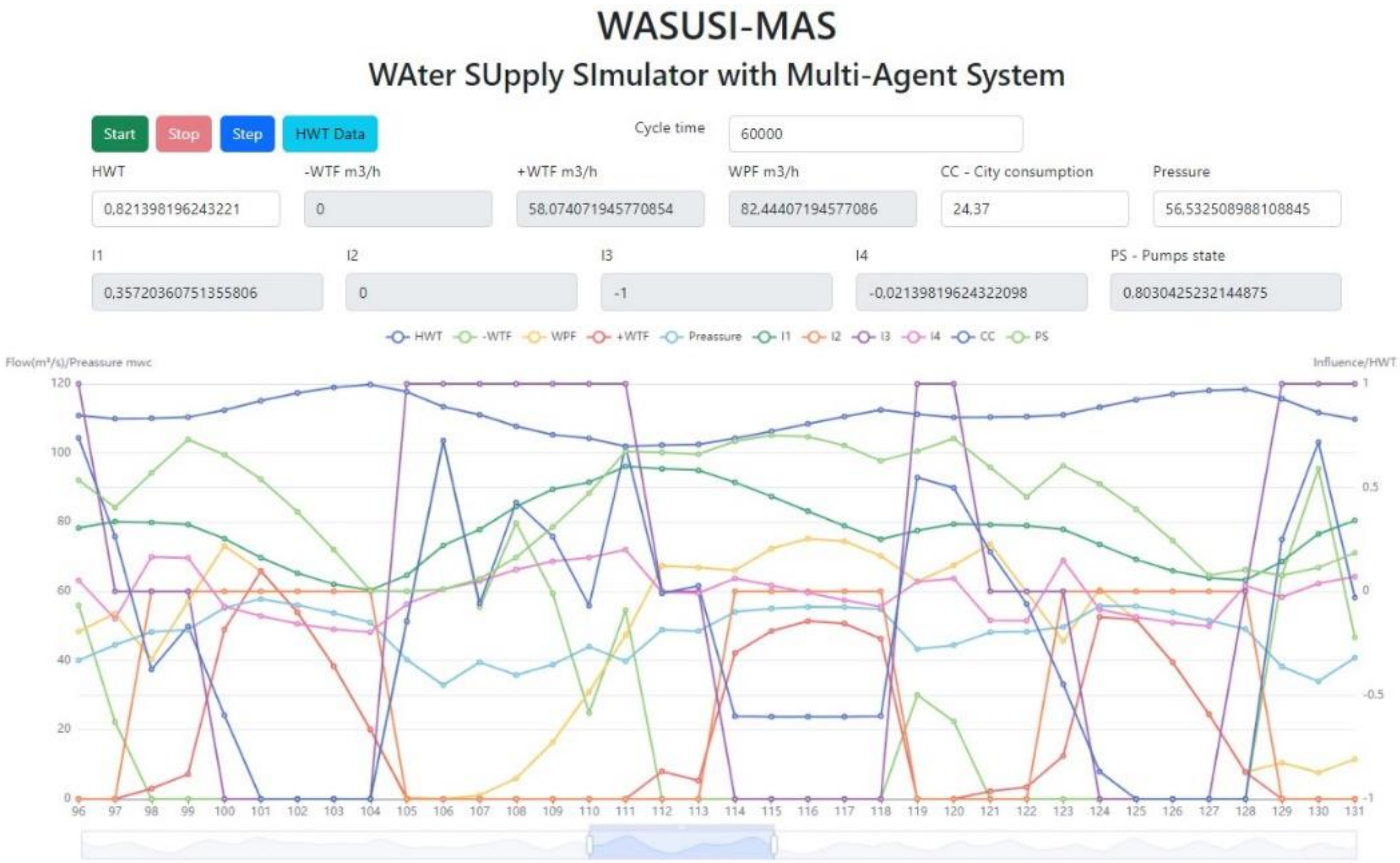
4. Multi-Agent System.

Element	Value
watchList	D_l, D_p y D_i
μ	0,1
FunD	$I_m = 0,5*D_l + 0,3*D_p + 0,2*D_i$
PostE	I_m



5. Proposed solution. Reactions.



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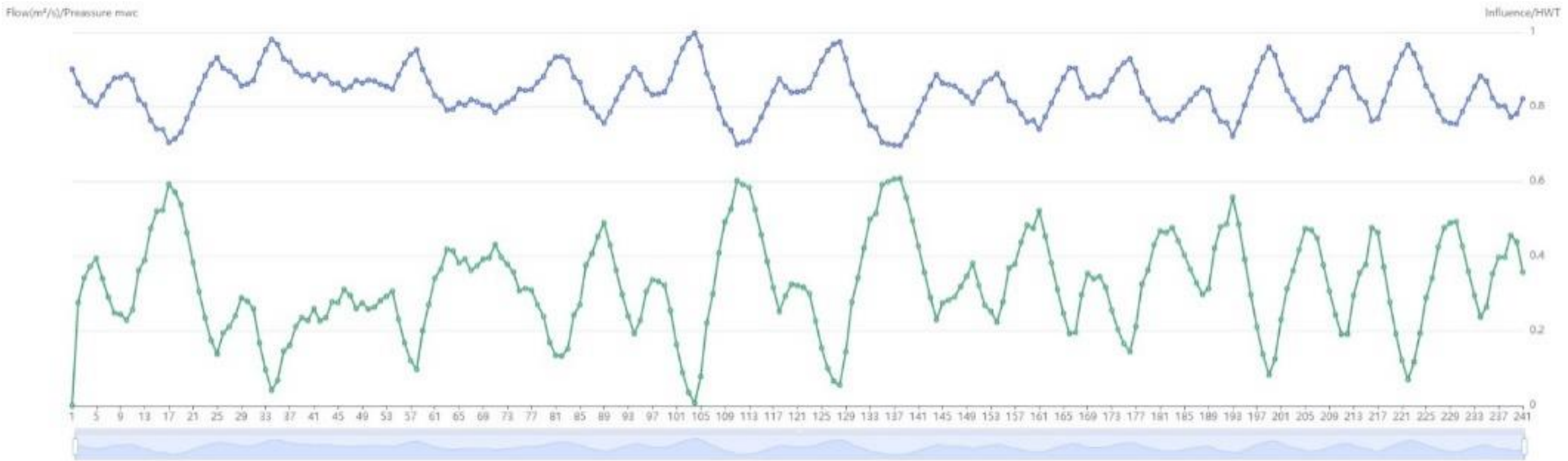

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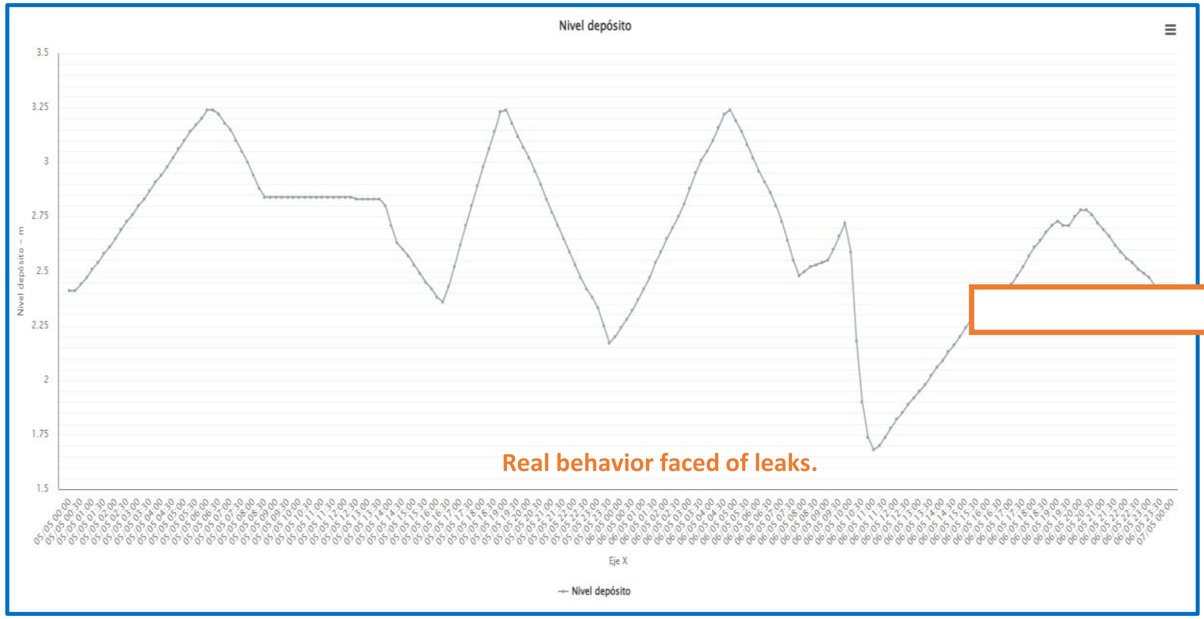
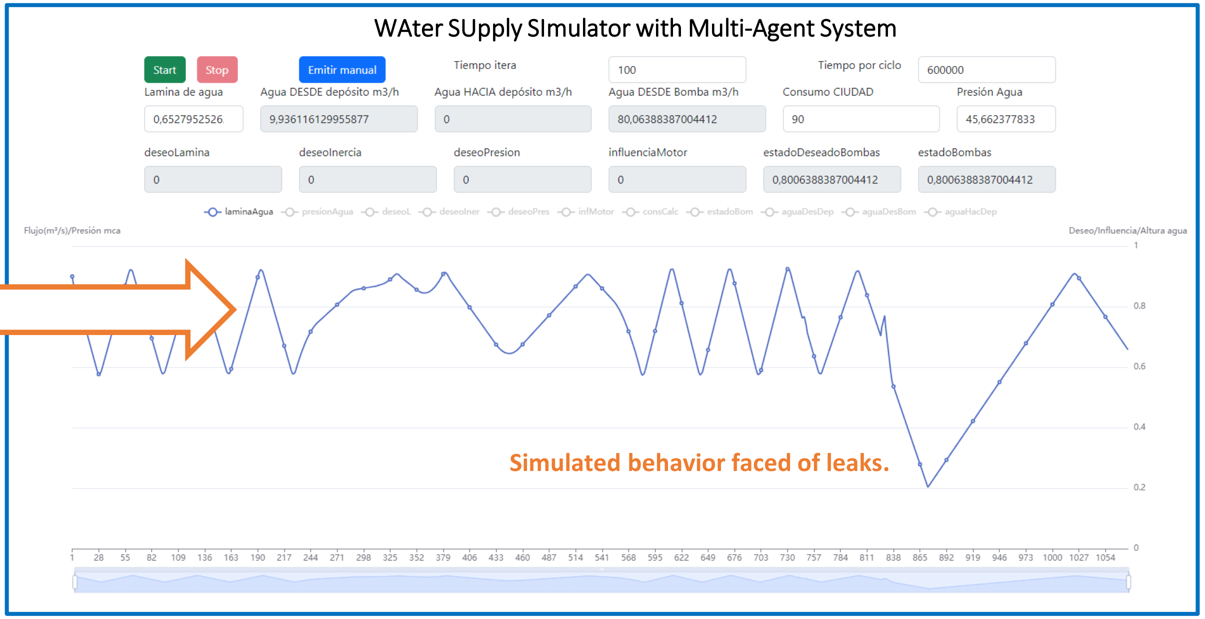


Real behavior faced of leaks.



Simulated behavior faced of leaks.

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6. Conclusions.

1. The results obtained show how the simulator is capable of maintaining the set objectives and handling unknown situations.
2. The simulator allows easily add interests. Make the system much more complex.
3. The system is based on the "divide and conquer" strategy. This strategy allows us to reflect infrastructures, no matter how complex they may be, and to observe their evolution.
4. It allows directing the behavior of supply systems towards a "just-in-time" approach. Optimizing the use and capabilities of each of the elements.
5. We **must to use a simulator, because is very dangerous and expensive** to aplicated directly the system in a real hydraulic system.

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