# Paramo and High-Andean Simulation using Reactive Agents
## *Hydrological Role of High Andean Ecosystems*

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Keywords: Ecosystems Simulation, Simple Reactive Agents, Artificial Intelligence.

Abstract: Ecosystems like Páramos and High-Andean forests have a very important role as regulators of the water process for the majority of rivers in Colombia. For this reason, a simulation, which shows the main functions performed by them, was developed. Simple reactive agents was the technique used in order to simulate these ecosystems and their components. the results obtained reaffirm the ecological importance both (paramos and High-Andean forests) for Equatorial countries.

# 1 INTRODUCTION

Colombia is a country with an exceptional natural wealth because it's conformed by diverse ecosystems, and geographic characteristics, which together make of it a unique country. Clear examples of this wealth are the paramos, ecosystems located at great heights in the equatorial zone and with a great ecological value for the countries that possess them (Russi et al., 2013).

Paramos are natural water regulators, thanks to theirs types of soil and vegetation, they can absorb the water of the rains and later release it towards the tributaries that feed the main rivers of the country. Also, those soils are covered by a great amount of organic matter that prevents the release of captured CO2 into the atmosphere (IUCN, 2010).

Although there's a lot of benefits that paramos give to Colombian population, some people don't take care of those fantastic and important places, and with activities like mining, agricultural expansion and afforestation they are damaging them (GREENPEACE, 2013).

Reasons like these motivate to the "Universidad Distrital Francisco José de Caldas"' complexity group to contribute with the paramos care, and actually, the group is into a developing project, about an application that simulates a paramo ecosystem using simple reactive agents.

The main goal is to develop a game where children can interact with nature ecosystems (as paramos, High-Andean forests), transform them in other kind of environments (mixed or urban ecosystems) and understand the positive or negative effects of such interaction. However, for this paper, the objective is only to make a model and simulation of the ecosystems logical part.

# 2 MODELLING ECOSYSTEM COMPONENTS

Simple reactive agents is the main technique used for modelling paramo components, given that this one is based on action and reaction processes, allowing the components interaction of a dynamic system (Vlahavas and Dimitris, 2005).

Basically, plants, rivers, soils, and other ecosystem components are modeled in this section, showing the main interactions of these components and defining their roles (sensor or effector) as reactive agents.

## 2.1 Modelling Photosynthesis of a Plant

Photosynthesis is a very important process made by the majority of the plants, which allow them make their own food and purify the air (Flexas et al., 2012), It is therefore required to build the representative model of the plant.

Analyzing the Figure 1, the interaction plant-air and plant-root is generated by the root (sensor) and leaves (sensor and effector) of the plant, and all the information obtained in such interaction is processed by the following control rules:



Morales, J. and Nieto, L.
Paramo and High-Andean Simulation using Reactive Agents - Hydrological Role of High Andean Ecosystems.
DOI: 10.5220/0006379301390143
In *Proceedings of the 2nd International Conference on Complexity, Future Information Systems and Risk (COMPLEXIS 2017)*, pages 139-143
ISBN: 978-989-758-244-8

- Leaves: If air has sunlight, then absorb $CO_2$ and sunlight, also if plant has water, then absorb water.
- Root: If water capability of plant isn't full, get water of soil
- Leaves: Generate glucose using photosynthesis general equation.
- Leaves: Release by-products from the photosynthesis process.

Photosynthesis process is based on the equation 1 (Palmeri et al., 2014), for this reason all the elements absorbed by the plant agent are measured in moles:

$$6CO_2+6H2O+\text{Photo energy} = C_6H_{12}O_6+6O_2 \quad (1)$$

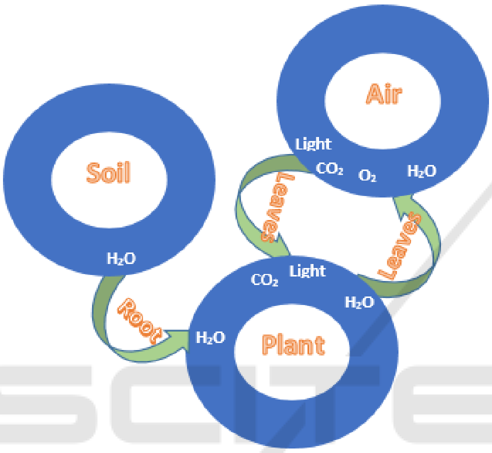


Figure 1: Model of plant using reactive agents.

## 2.2 Modelling Paramo and High Andean Forest Ecosystems

Colombian paramos have denoted characteristics like unique vegetation, soils and animals, and a lot of tributaries, lakes and creeks (Vásquez and Buitrago, 2011). However, this simulation is being focused only in the vegetal and hydrological part.

With respect to High Andean Forest (HA-forest), the main goal is to show the role that it plays as a water regulator and air purifier, because a large amount of water that is evaporated by the HA-forest to the environment returns in form of rain that falls on the paramos.

The main interactions of ecosystems are represented in the following figure.

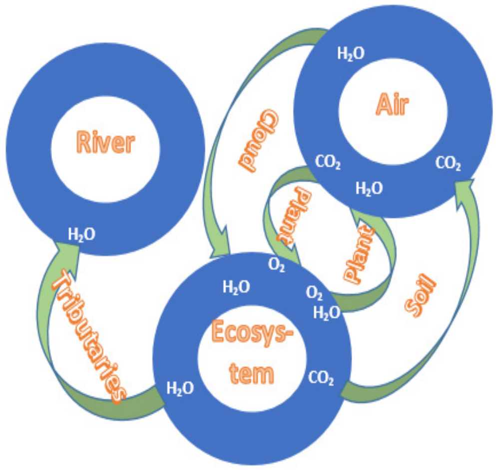


Figure 2: Model of paramo using reactive agents.

Ecosystem interaction (either paramo or high Andean forest) with the environment is represented by the Figure 2. The following rules of control are generated from this model:

- Plant: Through the photosynthesis process, plants release oxygen and water into the air.
- Soil: Absorb a percentage of rainwater and the rest is released to the tributaries. In the case of the paramos, their soils have the ability to retain rainwater and then release it slowly, this is the reason why paramos are so important in the hydrological process of Colombia (Díaz-Granados Ortiz et al., 2005).
- Tributaries: They collect all rainwater and water released by soils in order to transport it to rivers.

# 3 ECOSYSTEM COMPONENTS INTERACTION

Interactions of ecosystems are very important in order to understand how the simulation was developed. For this reason, the majority of such interactions are represented by activity diagrams showed in this section.

## 3.1 Territory Interactions

Taking into account the Territory entity as the main ecosystem formed by other ecosystems like paramos and High-Andean Forest, the Figure 3 represents the top level in the simulation. In this one, the different ecosystems, clouds and other components interact through time.

Time entity is composed of minutes, hours, and days. This entity verifies if is day or night changing the light state to day when hour=6 and night when hour=18 because in Equatorial countries like Colombia, days and nights are 12 hours each one.

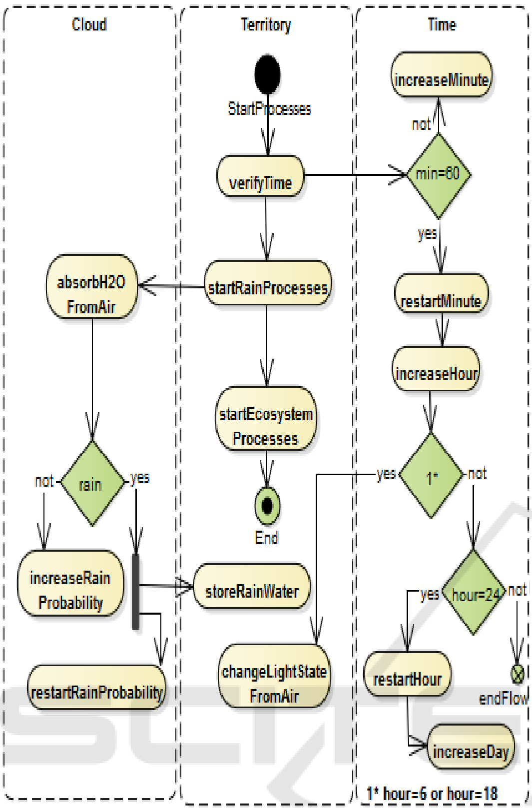


Figure 3: Territory activity diagram.

Finally, Cloud entity stores a certain amount of water from the Air entity, and if the variable rain is true then a rainfall percent is stored by the Territory entity. Else, the probability of rain is increased, this probability is given according to the day because every day represents a month of the year and so every day has a different probability.

These processes are performed repeatedly until the end of Day 12, which is the December representation. Then the Time entity is restarted.

## 3.2 Plant Interactions

Interaction of the Plant entity with its components is represented by the Figure 4, where main processes made by this one are photosynthesis and absorb water.

Photosynthesis is performed by the Leaves entity. Processes like absorb $CO_2$ from Air entity, absorb water from Plant entity and verify if the day variable is true are validated. Then, the glucose is made and $H_2O$ and $O_2$ are released into the Air entity. This process is performed only if the day variable has true value.

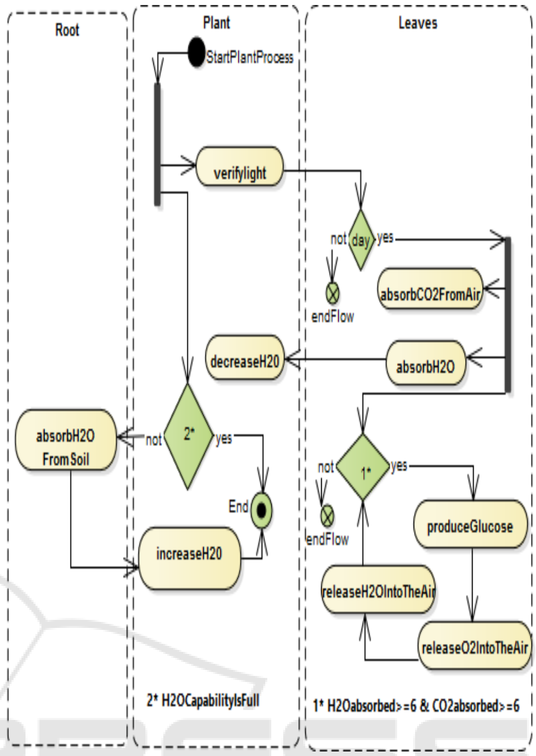


Figure 4: Plant activity diagram.

Absorb water is the second process, for this one The Plant entity verifies if the its water storage capacity is full. Else, the Root entity absorbs water from Soil entity increasing the water stored boy the Plant entity.

The Figure 4 represents internal interactions of the Plant entity. Nevertheless, the Figure 5 shows external interactions, allowing to observe the dependencies between this entity and other components.

## 3.3 Ecosystem Interactions

Perhaps, Figure 5 is the most important diagram because this shows the general interaction of the components. For example, plant processes, which allow you to understand how plants collect CO2 from the air and release water and oxygen into the air.

Other important aspect is the rainfall distributed between the soil and the river and how the soil also releases water into the river.

Both ecosystems (paramo and High-Andean forest) were simulated using the Ecosystem activity diagram and results obtained are exposed in the following section.

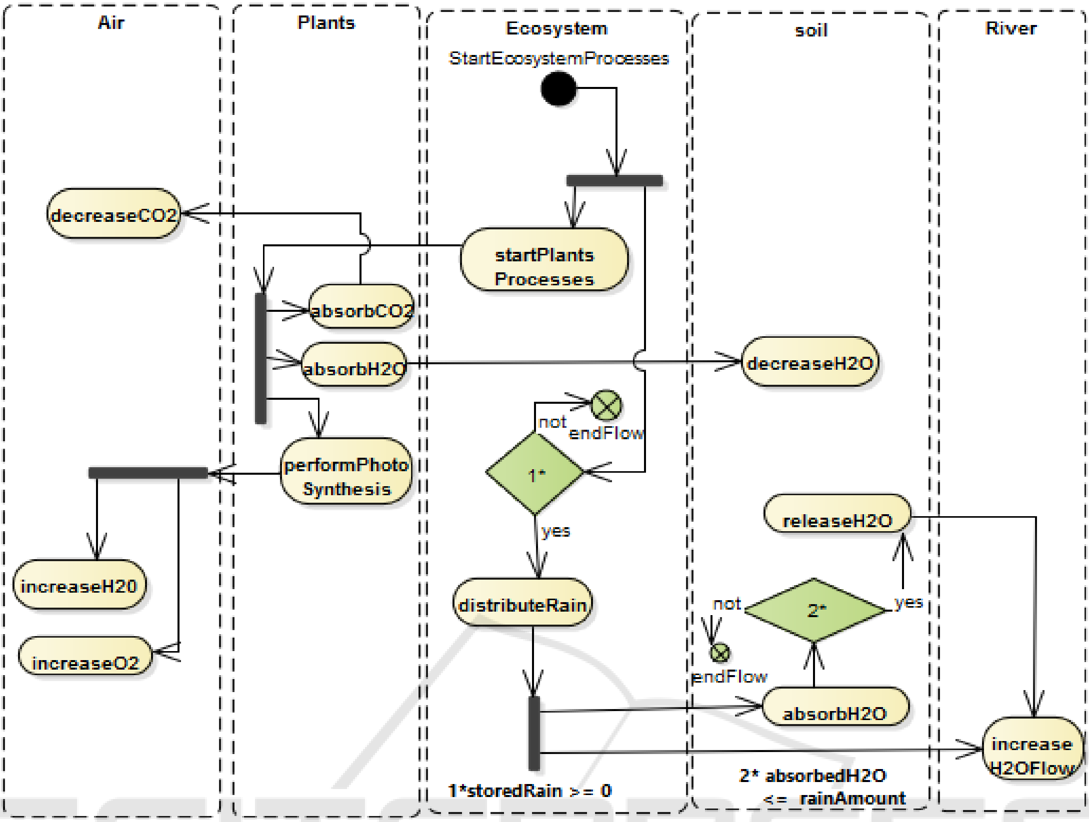


Figure 5: Ecosystem activity diagram.



## 4 RESULTS

In order to test different scenarios, were performed three simulations with the following characteristics:

Initially, the territory was simulated including both ecosystems, the paramo and high Andean forest, from this simulation the following data were obtained:

Table 1: Rain precipitation and river flow including Paramo & H-A Forest.

| Month | Rainfall(Lt) | Cabrera river flow(Lt/H) |
|---|---|---|
| 1 | 375,59 | 50,73 |
| 2 | 1230,04 | 30,81 |
| 3 | 4706,25 | 97,84 |
| 4 | 8896,34 | 118,37 |
| 5 | 10943,42 | 125,75 |
| 6 | 10142,84 | 122,21 |
| 7 | 13238,05 | 137,11 |
| 8 | 3272,27 | 108,36 |
| 9 | 3028,24 | 107,16 |
| 10 | 2499,72 | 106,19 |
| 11 | 2281,27 | 105,76 |
| 12 | 1581,46 | 104,12 |

When Table 1 is analyzed, the river flow has an average of about 100Lt in most months. With respect to the amount of rainfall, the period of greatest rainfall was between May and July, which is in agreement with the rainy season in the paramos (Díaz-Granados Ortiz et al., 2005).

The second simulation was done eliminating the organic matter and vegetation of the soil in the paramo, from this simulation the following results were obtained:

Table 2: Rain precipitation and river flow including only H-A Forest.

| Month | Rainfall(Lt) | Cabrera river flow(Lt/H) |
|---|---|---|
| 1 | 594,97 | 51,24 |
| 2 | 1594,52 | 50,69 |
| 3 | 4210,00 | 96,44 |
| 4 | 7522,20 | 198,82 |
| 5 | 10469,37 | 373,62 |
| 6 | 10847,70 | 366,72 |
| 7 | 14413,35 | 463,47 |
| 8 | 2396,23 | 95,53 |
| 9 | 3847,78 | 122,85 |
| 10 | 2446,71 | 58,64 |
| 11 | 3324,86 | 107,86 |
| 12 | 1192,23 | 66,34 |

The data in Table 2 are similar to Table 1 for the period of time in which the rainy season occurs, however, the river flow data varies abruptly in the Table 2.

Finally, the third simulation was done eliminating the highAndeanForest object. The data obtained are shown in the following table:

Table 3: Rain precipitation and river flow including only Paramo ecosystem.

| Month | Rainfall(Lt) | Cabrera river flow(Lt/H) |
|---|---|---|
| 1 | 108,26 | 44,23 |
| 2 | 194,71 | 3,80 |
| 3 | 540,59 | 12,02 |
| 4 | 467,19 | 23,67 |
| 5 | 1443,40 | 39,31 |
| 6 | 1713,36 | 54,60 |
| 7 | 2059,47 | 72,19 |
| 8 | 450,80 | 14,22 |
| 9 | 259,73 | 9,50 |
| 10 | 395,28 | 9,78 |
| 11 | 200,28 | 7,70 |
| 12 | 102,78 | 4,88 |

The third simulation shows a huge drop in the amount of rainfall recorded with respect to the previous simulations.

The following graph corresponds to the comparison of flow river, taking into account the data of Tables 1,2 and 3:

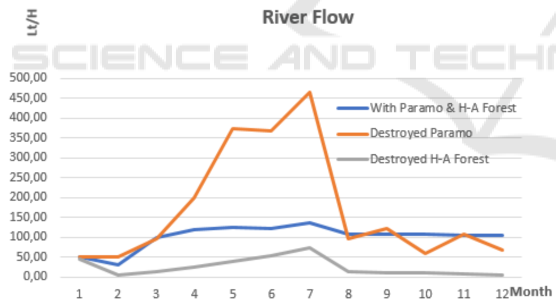


Figure 6: Comparison of the river flow for the simulation 1, 2 and 3.

Analyzing the Figure 6, it is observed that the flow of the river is balanced due to the interaction of both ecosystems (the paramo and high Andean forest), while in the simulation that includes only the high Andean forest the river flow undergoes drastic changes.

## 5 CONCLUSIONS

Observing the Figure 6, the importance of the paramos as regulators of the water cycle is evidenced, because in the rainy seasons they avoid that rivers flow grows in excessive form, whereas in the dry seasons they maintain the flow due to the water that is released periodically by them.

On the other hand, the data in Table 3 reflect the importance of high Andean forests because they evaporate a large amount of water, which then falls as rain over the paramos.

Reactive agents were necessary techniques in the simulation of ecosystems because they allowed to generate interaction of each component of the ecosystem with the environment, those simple interactions generated emergency, which is a characteristic of complex systems

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