Land use management using Multi-Agent Based Simulation in a watershed in south of the Brazil*

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Abstract. The change in land use in a region can have huge impacts on the environment. For land use management to be effective, it is necessary to explore the region of interest, its behavior, and the impact of each change. This study aims to present the development and simulation of an agent-based model for land use management in the Arroio Fragata Watershed, located in the south of Brazil. For this, regional data, maps of land use, and maps of sub-watersheds were used. And the agents were defined as managers who modify land uses in the region. Through some parameters and variables, a volume of water was defined that varied with each change in land use. The impact on the environment was analysed by varying the number of managers and land uses. The model generated satisfactory results and described the behavior of the agents and the environment according to the defined rules. It became conspicuous that some land uses to generate a greater impact, depending on the water consumption and the area of occupation in the region. In addition, some simulations showed that despite being the ones that resulted in the greatest changes in the environment, they were not the ones that generated the greatest impact.

Keywords: Land use management · Watershed · Multi-agent system.

1 Introduction

Land use management is the area that aims to organize and to plan the implementation of land occupation changes. Changes in land use induced by human actions have been seriously interfering with the environment, reflecting on the well-being of living beings and on the economy [4]. In addition, in watersheds, poor management of land use impacts the amount and quality of water resources, which are needed to carry out various activities, such as irrigation, public supply, leisure, and others [8].

Methods such as linear and non-linear programming, genetic optimization algorithm, game-based theory, among others, have been used to determine the

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ideal land use management in several regions [9]. Multiagent Systems (MAS) are tools that facilitate the construction of models on complex and dynamic environments, where agents perceive the environment and act on it [2]. An agent is an autonomous computational entity that acts from stimuli and sensors [12]. Thus, the decision making and interactions of agents generate changes in the environment, which affect their perceptions and decisions [13].

When computationally simulating a MAS, there is a technique called Multi-Agent Based Simulation (MABS), which makes it possible to describe the behavior of complex systems with multiple domains [6]. Thus, the behavior of land use change and human interactions in the environment can be simulated [11].

In this work, the development and results of a MABS are presented. The objective was to enable an initial study on land use management in a small watershed, located in southern Brazil. The model presented here was built using the GIS Agent-based Modeling Architecture (GAMA) tool, with available flow data, and maps of land use and sub-watersheds. The environment was discretized into regular cells. And in each cell, the land use and the sub-watershed were identified. From this, the agents defined as *managers*, modified the land use in each cell, in specific sub-watersheds.

To determine the impact of land use changes, some variables and parameters that interfered in the initial water volume of the environment were defined. A water consumption value for each land use was defined and determined in each cell. The model was defined with a monthly time scale, and a water recovery value was defined for each season of the year. In addition, the number of managers varied, as well as the intentions to change land use.

In the following section, the methodology is addressed, where the study region, the GAMA platform, and the construction of the system are presented. The results and discussion are in section 3, where some scenarios are addressed and analysed. And in section 4, are the final considerations of this study.

2 Methodology

2.1 Study area

The study region of this work is the Arroio Fragata Watershed (AFW), located in the extreme south of Brazil, with an area of approximately $216km^2$. AFW directly influences the Lagoa Mirim and Canal São Gonçalo Hydrographic Basin, which is a transboundary basin between Brazil and Uruguay. This has huge socioeconomic importance, due to the support of water supply for various activities. In Fig. 1, the AFW is illustrated, as well as its discretization in 39 sub-basins with different colors. The ArcLASH module of the Lavras Simulation of Hydrology model was used to make the spatial discretization of the region [1]. This tool was chosen with the intention of improving the MAS in the future.

In this work, we used the land use map obtained from the *Infraestrutura Nacional de Dados Espaciais* portal, available at [7]. The map is illustrated in Fig. 2, and presents 7 land use classes. The percentage of each use class in relation to AFW is: 50.1% agriculture; 4.5% exposed soil; 3.7% forest; 13.2% native forest; 4.8% native field; 22.9% pasture; and 0.8% water. Thus, agriculture and pasture represent the most predominant classes.

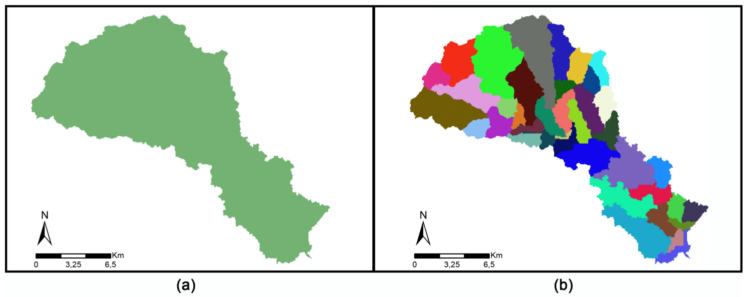

Fig. 1. Arroio Fragata Watershed: (a) region map; and (b) spatial discretization map in sub-watersheds.

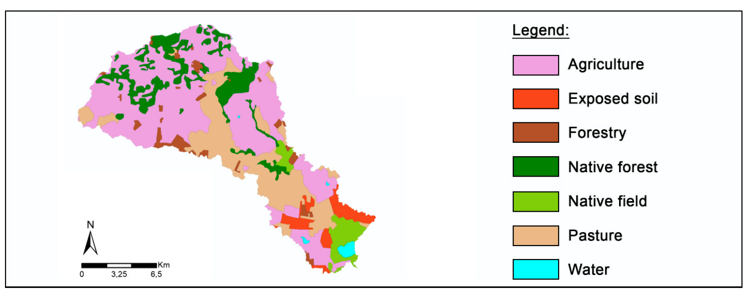

Fig. 2. Arroio Fragata Watershed: land use map.

2.2 GAMA platform

In this work, the GAMA tool was chosen for the modeling and simulation development of the MAS. GAMA is a platform based on the Eclipse tool, of which it is an integrated development environment [14]. In addition, it has its own programming language called GAma Modeling Language (GAML), which is coded using the Java computational environment. The platform provides several models, tutorials and online documentation.

Different types of datasets can be used to build MABS in GAMA, through an integrated development environment. The tool makes it possible to include data from the Geographic Information System, that is, it stores the geometry and attributes of mapped terrestrial data. The simulation environment can be defined in different ways, such as 2D, 3D, or graphical environment. Throughout the simulations, each agent can be inspected, and parameters can be modified. GAMA has been used to model and simulate multi-agent systems in the context of different types of problems, as in the works of [5, 3, 15, 10].

2.3 MABS development

The MABS, developed and presented in this work, has as the main objective to simulate the actions of agents on the management of land use and the impact on the environment. The MABS development involved verification, calibration and validation. These steps certify and guarantee that the model is close to the expected [2]. The verification was done at each stage of implementation of the rules of the environment and agents. The environment of the system is the AFW region, with its subdivision into 39 sub-watersheds, and the land uses. The environment is divided into square cells, and the dimensions can be modified before the start of the simulation through the parameter *Dimensions_of_the_cells*. However, in this work, cells that represent 300 meters in length were chosen, generating a mesh with 2574 occupied meshes.

The initial amount of water in the environment was defined as a volume of water (*vol_water*) with a value of 3000 (representing $3000 \times 10^7 L$). This amount was based on flow data, which are available on the Hidroweb[1] portal. From the flow data, the volumetric flow ratio was used to convert the data into volume, and define an initial value for the region. For each land use a water consumption value was defined, except for water land use. In Tab. 1 are the initial number of cells per land use and the water consumption.

Table 1. Water consumption by land use in each cell.

Land use	Water consumption	Number of cells	Initial total consumption
Agriculture	1.5	1287	1930.5
Exposed soil	1.2	125	150
Forest	1.0	111	111
Native forest	0.5	325	162.5
Native field	0.3	130	39
Pasture	0.8	576	460.8
Water	0	20	0
Total values:	–	2574	2853.8

Fig. 3 presents the simulation interface, which has the environment, parameters, 5 managers, and the grid mesh. The agents, called *managers*, can range from 1 to 10, this amount being determined by the parameter *Number_of_managers*. The agents represent institutions or organizations responsible for managing land

[1] https://www.snirh.gov.br/hidroweb/

use. As this is an initial study, it was decided to define a list of sub-basins for each manager, and a land use change objective called intention. In this way, each manager is responsible for changing land use in certain sub-basins, according to its intentions to change.

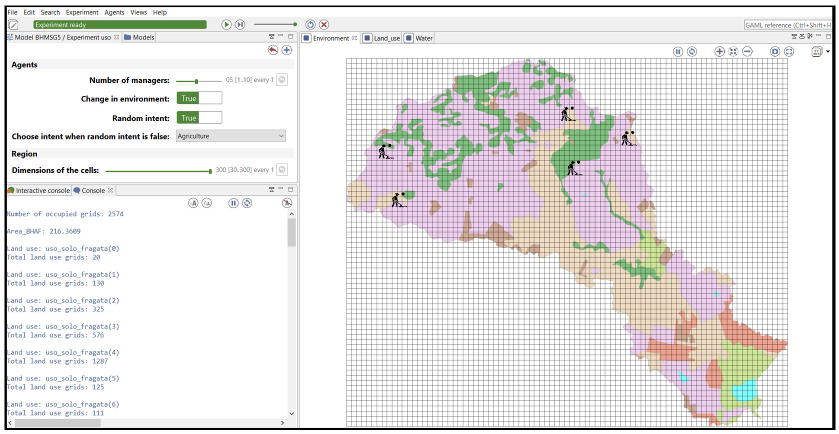

Fig. 3. MAS interface in GAMA.

The list of sub-basins for each manager is determined in an orderly method. First, the total number of sub-basins (39) is divided by the number of managers, which varies according to the parameter *Number_of_managers*. This result indicates the approximate amount of sub-watershed to each manager. For example, with the 39 sub-watersheds and 5 managers the division results in 4 managers responsible for 8 sub-watersheds, and 1 responsible for 7 sub-watershed. Sub-watersheds and managers are identified by fixed integers. The first sub-watersheds will be linked to the first manager, the following sub-watersheds to the second manager, and so on. Thus, all sub-watersheds will have a responsible manager and may suffer changes in land use. When starting the simulation, the managers are randomly positioned in one of their respective sub-watershed. Managers have two rules, which are "to move" and "to change" land use. Agents can move throughout the AFW, providing access to all of its sub-basins. For that, in GAMA, the wander action (move randomly) is defined, where the variables of speed (equal to 100) and amplitude of vision (45˙) are implemented.

The land use change can happen in all cells of the AFW. However, agents can modify land use only in their respective sub-watersheds. The intention of each manager is the desirable land use change. From among land uses, the intention is established between agriculture, exposed soil, forest, or pasture. This choice was made with the aim of analysing the impact of land use changes that generate more profitable values in real life. For this reason, the uses of native forest, native field, and water are not defined as the intention.

Each agent modifies the cells altering the land use from the intention. This attribute can be determined randomly or not. For each agent, one of the 4 land uses is defined randomly when the parameter *Random_intent* is true. When false, the intent that will be assigned to all agents is chosen before the simulation. Thus, when moving through the AFW, a manager acts by changing land use in cells that are included in one of its sub-basins, and that have land use different from its intention.

AFW is the environment of the MAS. In it, lists of 39 sub-basins and 7 land uses are determined. In addition, the total water volume and a water recovery rate are defined. In the data instance, there is a volume of water in the environment, calculated from the initial water volume, minus consumption. The time scale is defined as monthly. Thus, when the simulation starts, each cycle is equivalent to one month. Two actions were defined for the environment. Firstly, the water volume is updated in each cycle, from Eq. 1, where n is the reference month, V is the water volume, W is the water consumption sum and S is the water recovery rate.

$$\begin{cases} V_n = V_{n-1} - W_{n-1} + S_n, \\ V_0 = 3000, \quad W_0 = 2853.8. \end{cases} \tag{1}$$

The second action of the environment is to update the season every 3 cyclings. Thus, the water recovery rate is updated from to the season, which corresponds to approximately: 2650.99 in summer, 2945.99 in autumn, 3035.99 in winter, and 2785.99 in spring. These parameters were calibrated from tests during the simulations so that the system was stable when there was no change in land use, as illustrated in Fig. 4. To generate this study, the *Change_in_environment* option was inserted which, when false, does not allow agents to modify the environment. This stability does not match reality when there is no change in land use. This analysis was done only to calibrate the water recovery parameters.

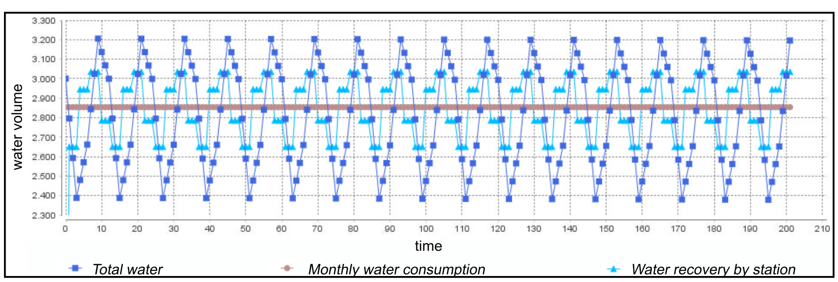

Fig. 4. Monthly amount of water in the environment without change.

In view of the system developed and presented, some scenarios were defined in order to generate discussions and to analyse the MABS. In Tab. 2, there is a summary of the proposed scenarios when agents modify land use in the environment. For each scenario, 10 simulations were performed, with 10000 cycles (months). This number of cycles was chosen so that it was possible to observe the behavior of the environment with a large change in land use. In addition, it aimed to verify cases of discrepancies in the results, that is when the water volume changes its behavior in terms of its increase or decrease. However, it is understood that this number of cycles cannot be considered realistic considering a monthly timescale. The simulations can be performed with a smaller number of cycles since in most scenarios the environment behavior is between 500 and 1000 cyclings.

First, the system was analysed when the change occurs for single land use, through 5 managers. In this case, there are 4 scenarios, one for each land use. Subsequently, the intention of the agents was defined as random, and the number of managers varied between 2, 5, and 10. The next section presents some results on the defined scenarios. Each scenario is commented on and verified according to the environment and the graphics generated at the end of the simulations.

Table 2. Determination of parameters for each scenario.

Scenario	Number of managers	Random intent	Intention
1	5	False	Agriculture
2	5	False	Exposed soil
3	5	False	Forest
4	5	False	Pasture
5	2	True	Random
6	5	True	Random
7	10	True	Random

3 Results and discussion

The first analysis was carried out for the first four scenarios. In Fig. 5 presents the environment after the change in land use during the 10000 cycles, for only one type of time (a) agriculture; (b) exposed soil; (c) forest; and (d) pasture.

Scenario 1 simulations generated expected results. A significant increase in the demand for water from the environment occurred when the shift was to agriculture. In this case, the simulations generated negative and decreasing water volume. Fig. 5(a) shows the AFW map after a change of approximately 510 cells to agriculture, which generated the highest water consumption in the scenario.

The volume of water for scenario 2 was decreasing in all simulations, since exposed soil is the second largest consumer of water in the system. In Fig. 5(b) there is the largest change in the environment for scenario 2, which corresponds to approximately 900 cells altered for exposed soil use. However, this case was not the one that generated greater consumption of water in the environment. Another experiment generated a huge consumption of water. In this case, the

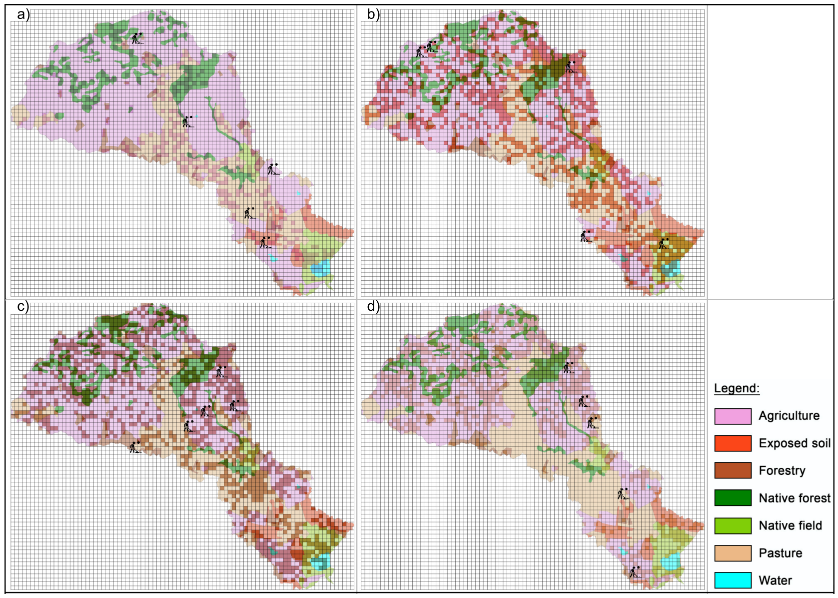

Fig. 5. Environment result for the first four scenarios, with change only to: (a) agriculture; (b) exposed soil; (c) forest; and (d) pasture.

change occurred in more cells with uses such as pasture and native forest, which generated a greater and faster demand for water.

In scenario 3, the water volume became positive and increased throughout simulations. Water consumption in the forest use is low when compared to agricultural use, whose region is predominant in the initial environment. Among the four initial scenarios, scenario 3 presented the case with the greatest change in the environment over the 10000 cyclings. The result of this experiment can be seen in Fig. 5(c), with approximately 950 cells with modified land use for the forest. However, this simulation was not the one that generated the lowest water consumption in the scenario.

Scenario 4 also showed an increasing water volume in the simulations. In addition, it generated the highest volumes of water in relation to the other experiments. In Fig. 5(b) we have the case where there was a greater change in the environment, with about 740 cells modified for pasture. However, in another case, the volume of water was higher where the change occurred predominantly in cells with native field uses (increased consumption), and agriculture and forest (reduced consumption).

Scenarios 5, 6 and 7 varied the number and intentions of agents. The number of agents directly interfered with the speed at which changes in land use occurred. The more agents involved in the system, the more changes occurred. In addition, the volume of water had lower final values (in the module) in scenario 5, and higher (in the module) in scenario 7.

In scenario 5, with 2 agents, the biggest change occurred in the case where the intentions were exposed soil (roughly 300 modified cells) and forest (roughly 130 modified cells). In this case, the water volume became negative and decreased. However, another situation generated higher water consumption (see Fig. 6(b)). Overall, out of 10 simulations this scenario presented 4 with negative final water volume and 6 with positive final water volume. In situations where the volume of water was negative, the intentions involved agriculture or exposed soil. However, when the simulation involved these two intentions, but the changes were smaller for these uses, the system demanded less water. In Fig. 6 there are graphs of the volume of water for two cases.

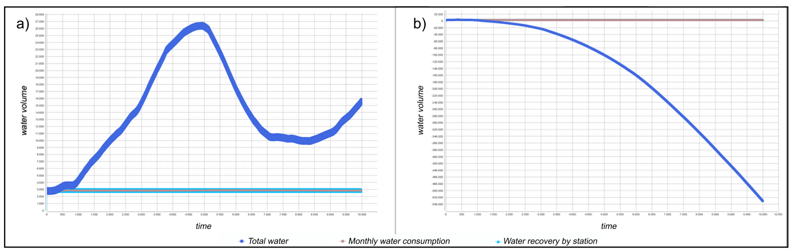

Fig. 6. Graphs of water in the environment, with intentions: (a) forest (roughly 350 modified cells) and agriculture (roughly 50 modified cells); and agriculture (roughly 185 modified cells) and pasture (roughly 105 modified cells).

In scenario 6, 5 agents modified the environment. Among the 10 simulations, the final water volume was positive in 6, and negative in 4. However, 2 simulations presented negative values and positive values for the volume of water. The biggest change occurred when the intentions of agents were forest (approximately 430 modified cells), pasture (approximately 380 modified cells) and agriculture (approximately 170 modified cells). In this case, the volume of water decreased by 6500 cyclings. Then the water consumption decreased, and the water volume became positive and increased. It can be seen that the change from use to agriculture was low, and the number of cells with this use decreased throughout the simulation. The smallest volume of water occurred in the simulation where changes were for exposed soil (about 205 modified cells), agriculture (about 195 modified cells), forest (about 145 modified cells), and pasture (about 145 modified cells). approximately 125 modified cells).

Among the 7 scenarios presented, the case that generated the greatest change in land use was the one that had a modification of approximately 740 cells for exposed soil, 580 cells for the forest, and 80 cells for pasture. This was one of the cases of scenario 7 and can be seen in Fig 7, where the environment, water volume, and land use change graphs are shown. The smallest water volume also occurred in a simulation of scenario 7, where the change involved exposed soil (approximately 450 modified cells), agriculture (approximately 370 modified cells) and forest (approximately 120 modified cells). In scenario 7, 6 simulations generated negative and decreasing water volume. In addition, 5 simulations involved the 4 possible land uses, 3 of them with negative final water volume.

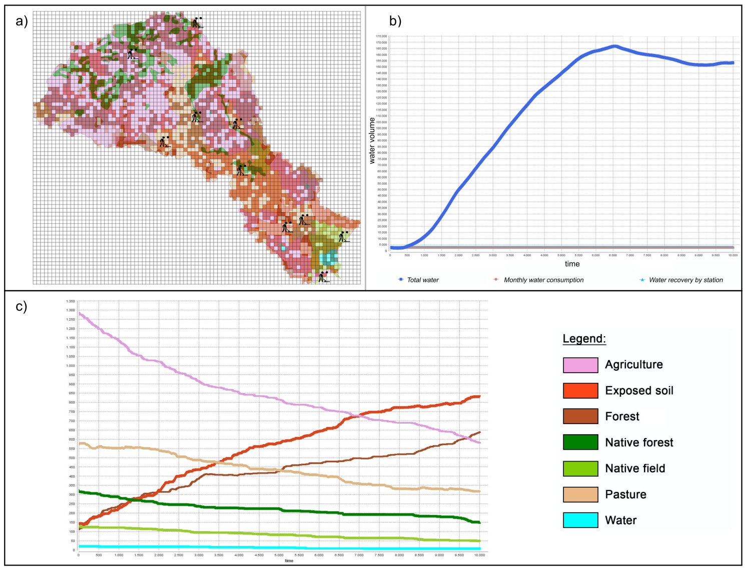

Fig. 7. Results for the simulation with the most land use change: (a) environment; (b) volume of water; and (c) amount of each land use.

The results showed that the MABS developed fulfilled the objective, which was to simulate the change in land use and the impact on the environment. The regions that generated the most impact on the volume of water were not necessarily the ones that had the greatest change in land use. In most cases, when cells were modified in greater quantity for agricultural uses or exposed soil, the water volume decreased and was not recovered. On the other hand, when the biggest changes were to pasture or forest, the system tended to decrease consumption and increase the volume of water. These analyses show that the system had good results from the developed MABS and its rules. In the next section, some conclusions and future works are presented, where some challenges and proposals for improvements in the model are commented on.

4 Conclusion

This work presented a study of land use management in AFW using MABS. The model was developed and simulated on the GAMA platform, from which it was possible to implement data from the study region. Some scenarios were determined from the cases of random intent or not, and from the modification in the number of agents. To verified the results, the graphs, the changes in land use involved, and the respective water costs were analysed with the expected results and each scenario.

Through the simulations of the actions of the agents on the environment, it was possible to visualize the changes in land use at each cycle. In addition, graphs presented the results of the total water volume in the environment and of the final amounts of each land use. Thus, the MABS in GAMA generated an initial study, which in the future may serve as a support tool for the decision makings of land use management. The results from the system and agents rules were satisfactory, and the change in the environment occurred as expected. However, some difficulties were faced from the development and simulation of the model, such as the determination of parameters, the computational time, and the validation.

The model data, such as water volume and water recovery rate, were based on real data. However, the values were adjusted so that the model was better calibrated. Also, seasonal water recovery rates were defined as constant values. In future works, it is expected to develop a tool that more effectively simulates the hydrological behavior of the model. For this, it is intended to couple the MABS to a hydrological model, which will simulate the behavior of the hydrological processes involved in the region.

Another challenge faced was the computational time of the model. The simulation proved to be fast for simulations of up to 10000 cyclings. However, in some cases where the simulations had more cycles, some graphs were not generated. A future objective will be to be able to simulate land use change across the environment, to determine the volume of water at the end of the simulation and the runtime. In addition, it is expected to obtain a model for watersheds with larger areas, in order to explore other important water catchment regions. For this, more data, rules and information in the system will be considered.

In this work, the agents interacted only with the environment. With this, it was possible to explore the division of sub-watersheds by agents, the number of managers, the change in land use in each cell, and the change in the environment according to the variables involved. However, it is important that in future works agents can communicate and cooperate to achieve their goals. This way, agents will be able to act and make decisions about land use management. Also, some characteristics can be determined to managers, such as production rate, cost per product, and the possibility of modifying land use in sub-watersheds of neighboring managers. Thus, the system would have rules that are more solid and closer to reality. In addition, in order to validate the model, it is expected to analyse trends in land use change over the last few years. With this, agents will have intentions that follow trends in specific AFW regions. From this, other studies can be explored.

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