Dynamic Modeling for land use and land cover changes in sub-basin of Arroio Grande, Rio Grande do Sul - Brazil.

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Keywords: dynamic modeling, remote sensing, digital image classification.

SUMMARY

The micro-basin of Arroio Grande, situated within the state of Rio Grande do Sul, Brazil, had its occupation initiated in the second half of the XIX century with the arrival of the Italian immigrants, being intensified at the end of the same century with the increase of agricultural activities, wooden extraction, and commerce driven by these sectors. Studies in the area showed a local tendency of increase of the forest areas, the agricultural activities and the reduction of field areas, in the last two decades. This study aimed to model the dynamic of use and covering of the land in two periods of time: 1991 to 2002 and 2002 to 2011; and the simulation of sceneries for the year of 2020. For preparation of the thematic maps of use and covering there were classified images of the sensors TM and ETM of the satellites Landsat 5 and Landsat 7. The modeling process was performed in the applications program Dinamica EGO through the methods: Chains of Markov, Weights of Evidence and Cellular Automata. The simulated maps for the years of 2002 and 2011, when compared with the real maps, reached rates of similarity *fuzzy* superior to 0,95 %. The modeling process allowed the identification of transitions of use between the selected classes, indicating to expansion, retraction and the crops rotations of use in the area of the micro-basin. The scenery simulated for the year of 2020 presented percentages of changes of use and covering significantly less than the checked for the previous periods, predicting increases of 2,64 % and 4,38 %, for the forest and agricultural areas, respectively, and a reduction of the areas of field in the order of 8,19 %. This alteration in the development pattern of the use of the land in the area of study indicates a probable stagnation from the advancement of the agriculture, due to the absence of more areas adapted for the activity, as soon as this one already occupies great extensions of the area of the micro-basin.

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1. INTRODUCTION

Located between the physiographic areas of the Central Depression and Southern Tableland of Rio Grande do Sul, Brazil, the hydrographic micro-hydrological basin of the Arroio Grande, have more than 35 000 hectares and integrates the hydrographic sub-hydrological basin of the Vacacaí-mirim River.

The occupation of the area date from the second half of the XIX century, with the arrival of the Italian immigrants, being intensified in the end of the same century with the increase of the agricultural activities, wooden extraction, and the commerce driven by these sectors. The area is composed at present by four cities: Silveira Martins, Itaara, Santa Maria and Júlio de Castilhos, having the first two their municipal thirsts located in the basin area.

The region is characterized for the most quantity of small farms, most of them devoted to the mixed farming (RUHOFF, 2004). According to Itaqui (2002), Ruhoff (2004) the agriculture in the Arroio Grande strongly occupied until the sixties areas of the slopes of the mountain ranges; this reality changed with the “ Green Revolution ” and the access to technological and the agricultural mechanization, and the areas of declivity were abandoned, returning then for more appropriate areas to the use of the mechanization. The corresponding areas to flood plain of the Arroio Grande are widely used, up to the current days, for the cultivation of irrigated rice, practice spread and financed in the seventies by the “Programa Nacional para Aproveitamento de Várzeas Irrigáveis – Pró-Várzea”, which took as an objective the adaptation of the wetlands for agricultural production (DIEGUES, 1990; DUARTE; TAVARES, 2007).

Previous works in the area of the hydrographic sub-hydrological basin of the Arroio Grande, like Ruhoff (2004) which was dedicated to referring questions to the modeling of the superficial drainage and the loss of grounds, and Kleinpaul (2005) and Torres (2011) that had the objective to analyze the forest evolution, they identified increase in the areas of forest and reduction of the areas of fields and pastures. According to the authors the increase of the forest area is attributed to the abandon of the near areas the slopes of the Southern Tableland for more intensive occupation of most favorable areas the agricultural mechanized activities, factor that justifies equally the reduction of the areas of field.

In this context, the term “land use” is related to the anthropic action. Skole (1994) affirms that the land use is the human job from a certain covering of the land, the way for which the human activity appropriates of the results of the primary liquid, conformable production determined by a complex of socioeconomic factors. The term “change of land use”, for Briassoulis (2000), means quantitative transformations in the area (increase or reduction) of a given type of land use. According to the author, the change of use can still wrap his conversion for another, or the modification of certain type of use in his development standard of the same use and, so, be modified in a forming system of the scenery.

Analyses about changes of use and cover are essential to the development of sceneries who aim the local and regional sustainability. Pedrosa (2004) proposes the use of dynamic space models for such, and those will have to describe the evolution of space standards of a system along the time. A dynamic space model, for Burrough and McDonnel (1998), understands a mathematical representation of a process of the real world, in which a location in the silent land surface in reply to variations in the coercive ones of such a process.

This work have as objective the use of tools of modeling to analyze dynamic space-time in the micro-basin of the Arroio Grande, Rio Grande do Sul, between the years of 1991 to 2011 and on basis of this model, project future sceneries of use and covering of the land.

2. BACKGROUND

The dynamic models of space simulation appear with the intention of introducing a new way of understanding the geographical space, making possible to include the dynamic processes in the space analysis (ROCHA; SOUZA; TENEDÓRIO; 2001). To Rodrigues, Soares-filho and Costa (2007), dynamic models of space simulation has by objective support the analyses for the understanding of the environmental systems, taking into account all the processes involved, to be able to determine them how they evolve before different sceneries (socioeconomic, political and environmental). These models reproduce spatial patterns of changes and are of vital importance for the understanding and evaluation of environmental complex questions for such in the local and global extent (SOARES-FILHO; et al., 2004).

The models of change and use of land cover give support to the studies about causes and consequences of these alterations and help in the esteem of the impacts of the supposed changes (Costanza and Ruth 1998 apud Verburg, 2004; Veldkamp; Lambin (2001)). The analysis of sceneries prepared from these models of use of the land can give support to the projection and the management of the politics of use of the land. According to Soares-Filho; et al., (2004), the result of a model of space simulation allows that hypotheses are tested for the prediction of sceneries, who for his time contribute strongly with the projection to middle and long term.

Dynamic models of use and cover of the land, it has been having great distinction in the last years, many works are dedicated to these models, looking to overcome of the statistic analyses, insufficient for the analyses of dynamic processes like the evolution of the scenery (SOARES-FILHO; PENNACHIN; CERQUEIRA, 2002), urbane evolution (ALMEIDA; et al. 2003), advance of the forest deforestation (GARCIA; SOARES-FILHO; MORO, 2004), changes the forest covering (HENDGES, 2007; PEREIRA; BENEDETTI; ALMEIDA, 2011), land use and changes of land cover (SERRATO; et al, 2011).

An extensive categorization of generic models of changes of land use is introduced by Briassoulis (2000). According to the author, the models can be classified, in view of his methodological and functional aspects, in: statistical or econometric;

models of space interaction; models of optimization (including linear, dynamic, hierarchical and non-linear planning as well as models of maximization of usefulness and model multi-criteria of taking decision); integrated models (models of gravity, of simulation and of entry-exit); models based on natural sciences; models based on SIG and models based on Chains of Markov.

2.1 Markov Chains

The Markov Chains are empiric mathematic models, able to describe stochastic processes (Pedrosa e Câmara, 2007). The markovian model can to be expressed for the matrix notation, denoted as Baker (1989):

$$\Pi\ (t+1) = P^n \cdot \Pi\ (t)$$

In: Π (t) is the system state at time t, Π (t+1) is the system state at time t+1 and P^n

The changes are likely to occur, represented in the probability matrix of the transition decomposed in time step. This matrix transition account the probability of the state *i*, stay the same or change to state j during time t-> t +1.

The advantage in using the Markov chain is the possibility of their parameters are easily estimated statistically from a sample of transitions occurring during a time interval. Due to its simplicity, it is only required to define a finite number of states and the knowledge of transition probabilities (NOVAES, 2010).

As in nature, the Markov process models the change of land use from a multi-directional way, i.e., plots of land can in theory change from one category of land use mutually exclusive to any one at one time (SOARES-FILHO, 1998). The main advantages of the Markov chains are the wide operational simplicity and mathematical ease of application data from remote sensing, a simple integration with GIS environments, and the fact does not require a lot of old data to predict the future (PEDROSA; CÂMARA, 2002).

The method of Markov chains has limitations mainly because the model restricting the response space and do not explain the phenomenon, however, is able to make predictions, provided that their processes are stationary (PEDROSA; CÂMARA, 2002). These limitations can be removed, According to Lambin (1994) many approaches can be used to overcome the main limitations of Markov chains in dynamic modeling, incorporating regression models, logistics, among others.

2.2 Cellular Automata

Models based on cellular automata were introduced by John Von Neumann and Alan Turing to study processes of growth and self-reproduction. The application of the spatial model based in Cellular automata begun in the Quantitative Geography, mainly with work of Waldo Tobler (WHITE; ENGELEN; ULJEE (2000); ALMEIDA, et al (2007)).

Models this type consist of a matrix cellular infinity, having discrete states equivalent where each cell is connected to its immediate surroundings. The transitions rules is the same for each cell, and the cellular structure is functionally homogeneous (ROCHA et al., 2001; GREMONINI e VICENTINI, 2008; WHITE et. al, 2000; SOARES-FILHO et al., 2002; BURROUGH e McDONNEL, 1998). Any system with many identical elements that interact locally and can be modeled using cellular automata deterministically (ROCHA et al., 2001).

Cellular Automata are composed of four basic elements: cells, states, neighborhood and transition rules (BATTY et al., 1997 apud ALMEIDA, et al 2007). The cells are adjacent objects and can take different shapes and dimensions; states are the discrete attribute of each cell; and the surrounding conditions change influence cell may be of different formats (cross or Von Neumann neighborhood, window or 3x3 Moore neighborhood, etc.), the transition rules are uniform and applied in all cells, or neighboring states (ALMEIDA, et al 2007).

3. METHODOLOGY

According MAS et al., (2011) the procedures involved in the modeling can to be describe in five steps: (1) calculate the area of each transition; (2) determination of the probability of change; (3) component indicating the location of changes; (4) eventually a space module that simulates the spatial patterns of changes and (5) a procedure for comparing the reference map with the map simulated. The first three steps consisting in said calibration step later in the article, the fourth step in the application stage of the model and the final in the validation of the model performed. The methodology described below considers such steps to elucidate the construction and execution of the model.

3.1 Maps of static and dynamic variables

The design of the spatial model in *Dinamica EGO* requires the definition of two different types of thematic maps. The first, due to its time-space variation in the period of analysis, called "dynamic variables" in the modeling process. The second type includes maps "statistic variables", so called because they disregard the occurrence of processes of transition in their classes during the analyzed period.

According Veldkamp and Lambin (2001) for the development of more realistic land change models use is essential to identify the most important drivers of change. Just as it's essential to understand how the scale of analysis affects modeling results; differentiate between the projections of changes regarding the amount and location, because while some models have focused on prediction of rates of change, others put more emphasis on spatial patterns. This also brings implications in the choice of data and validation strategies.

For dynamic variables thematic maps were prepared for use and land cover from the technique of digital classification of Landsat images. The Landsat series of satellites aims to provide data for environmental studies and is widely used in mapping of natural resources, because its sensors *Tematic mapper - TM and Enhanced Thematic Mapper - ETM*, have good radiometric resolution (28 bits) and space (30 meters), to regional studies, medium scale and requiring good temporal resolution (16 days). In this work we used a series of three dates for the summer of 1991, 2002 and 2011. For the years 1991 and 2011 were used Landsat 5 TM sensor 5, 2002 and used the Landsat 7 ETM +.

The georeferencing and image classification were carried out in SPRING software (System for Georeferenced Information Processing), developed by the National Institute for Space Research (INPE). The classification was done so supervised with the aid of segmentation by regions, and the classifier algorithm was adopted Battacharya.

Maps statistic variables were also prepared in this application, and we can divide them into two types according to their origins: natural or anthropogenic, which correspond, respectively, slope and drainage network, and access roads as main roads, secondary and railroads. To elaborate the map of slope and drainage network extraction were used radar data from Shuttle Radar Topography Mission-SRTM (NASA, 2011), the others were digitalized using topographical maps and satellite images.

3.2 Dynamic Modeling

The model was implemented in the Dinamica EGO application, developed by the Department of Remote Sensing, Federal University of Minas Gerais – UFMG, Brazil, in order to enable the construction and implementation of models for dynamic studies of landscape and environmental modeling (SOARES-FILHO; RODRIGUES; COSTA, 2009). As previously mentioned, the design of the model involves three distinct steps are described below. calibration of the model being used, run the model and its validation.

3.2.1 <u>Calibration of the model</u>

The calibration model involves calculating taxes of transition from the classes of land use and land cover (Table 1) were generated for which two matrixes, multiple and simple, the first comprises transitions occur annually and second transitions observed throughout the period of analysis. To define the transition matrixes, the Markov method is used for Dinamica EGO.

The calibration step is also composed by the calculation of transition probabilities between classes of maps of static and dynamic variables, for which we use the method of Weights of Evidence. This method is based on Bayesian probability theorem, based on Bayes' theorem that determines the possibility of occurrence of an event, given the prior occurrence of an evidence (BONHAM-CARTER, 1994).

Table 1. Transition matrices for simple step and multistep for the time series from 1991 to 2002 and from 2002 to 2011.

Transition		**1991-2002**	
Of	**To**	***Single Step***	***Multi Step***
Forest	Field	0.1070403199	0.01318074854

Forest	Agricultural use	0.03706688155	0.002119729206
Field	Forest	0.1573897986	0.01873791136
Field	Agricultural use	0.2615001367	0.04398651453
Agricultural use	Forest	0.09646479863	0.007372688804
Agricultural use	Field	0.355796592	0.05958485846
Transition		**2002-2011**	
Of	**To**	***Single Step***	***Multi Step***
Forest	Field	0.09736738344	0.01470341556
Forest	Agricultural use	0.03326342737	0.002229871116
Field	Forest	0.1758382562	0.02529109198
Field	Agricultural use	0.2572167137	0.04527245417
Agricultural use	Forest	0.09746629275	0.01022843404
Agricultural use	Field	0.2182368141	0.03793385165

3.2.2 Running the model using Cellular Automata (CA)

The Dinamica EGO uses the Cellular Automata (CA) method as a model of spatial simulation, the input parameters are thematic maps of the landscape (usually derived from remote sensing data), represented by a matrix. In the modeling process implemented in this application are considered spatial variables classified into dynamic and static (SOARES-FILHO, 2001). The structure of the Dinamica EGO is based on "functors", the procedure for allocation changes. It uses two complementary processes, the functor Expander, which is a function responsible for expansion and contraction of the thematic classes of patches, and Patcher, responsible for the formation of new patches. Within these "functors" are defined algorithms for the average size of the patches, the variance and the isometry of the patches. The index of isometric ranges from 0 to 2, and stains acquire a more isometric shape when the value approaches 2 (SOARES-FILHO; RODRIGUES; COSTA, 2009).

3.2.3 Validation of simulation model

The systematic validation of simulation modeling jobs generated in use and land cover is a key step for the research (VELDKAMP, LAMBIN, 2001). **The validation process model space must be made by methods of comparison based on proximity, since they do not coincide cell by cell, may have patterns of similarity** SOARES-FILHO; RODRIGUES; COSTA; 2009).

The method used in the application Dinamica EGO consists of an adaptation of the method Hagen (2003) apud Soares-Filho et al. (2005), its uses similarity measures for fuzzy logic applied in the context of the local neighborhood on the actual maps and simulated maps. The functions of exponential decay and decay constant are applied when comparing the two maps in two ways, i.e., we have a map of similarity of the first map that is related to the second, among the values, you chose the lower value. The resulting maps this method presents only cells that have not changed in comparison, as can be seen in the equation:

if(i1=i2) then null else i2

Where: i1 and i2 are, respectively, map 1 and map 2.

3.2.4 Simulation of future scenario

The scenarios simulation until the year 2020 was performed using the parameters of "Expander" and "Patcher" validated in simulation the year 2011. How to map into the model was used to map land use and land cover the year 2011, the process resulted in nine annual statements for the period 2012 to 2020.

4. RESULTS AND DISCUSSION

4.1 Classification of digital land use and land cover

The classification of land use and land cover from Landsat images (Figure 1) explains the trend of landscape evolution in micro-basin of the Arroio Grande. As can be observed in Table 2 is a significant increase of forest areas and the class of agricultural use occurring, therefore, a decrease of the field areas.

Between 1991 and 2002 forest areas increased by 4.49%, the areas of agricultural use 37.21% and 18.08% decrease in fields. Between 2002 and 2011 the tendency remains, and the forests have increased at a rate similar to the previous period 4.98%, as agricultural areas had a less significant increase being 17.87% and a reduction in the field presents a slight decrease compared to the previous index, 17.30%.

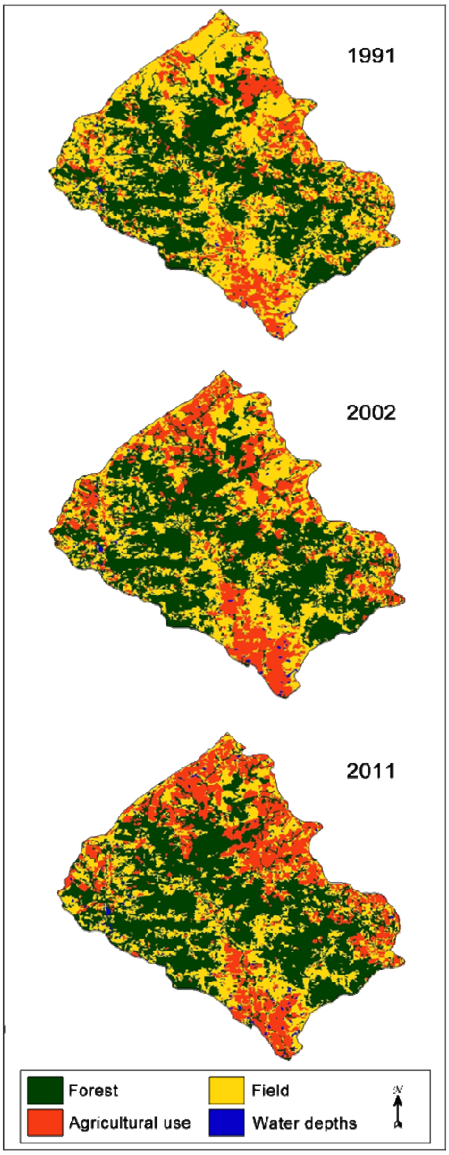


Figure 1. Thematic maps land use and land cover in micro-basin of Arroio Grande in 1991, 2002 and 2011.

Table 2. Evolution of land use and land cover in the micro-basin of Arroio Grande.

Thematic class	1991 (ha)	2002 (ha)	2011 (ha)
Forest	15078.15	15735.625	16517.07
Field	14812.65	12103.625	9959.85
Agricultural use	5376.78	7339.3125	8652.15
Water shade	89.64	173.3125	231.3

RUHOFF (2004) in study in this same area to investigate the dynamics of land use and land cover classification through the vegetation index NDVI (Normalized Difference Vegetation Index) to determine rates of soil loss, this author observed a general increase in forest cover, between 1987 and 2002, in the order of 5.05%. RUHOFF (2004) also found changes in agriculture, where crops remained in floodplains, there was a decrease in the areas of the plateau and increase Flange on top of the Southern Plateau, noting also the reduction in the areas of field and pasture. The author argues that technological advances in agriculture led to the displacement of crops for flatter areas with greater potential for agriculture.

4.2 Simulations land use and land cover dynamics in the application Dinamica EGO

As mentioned before, the algorithms used by the application of Dinamica EGO to make the dynamic transition are "functors" Expander and Patcher, respectively responsible by expansion and contraction of patches, as well as the appearance of new patches. In these "functors" set to the average size of patches, stains and the variances of the isometry.

Simulation models for the years 2002 and 2011 values were used for the Expander and Patcher equal to 3.6 ha for both medium size, as for the variance of the patches, and isometry equal to 1.6 to Expander and 1, 5 to Pachter.

The resulting simulations of the dynamic modeling of land use and land cover made in the application Dinamica EGO for the years 2002 and 2011 showed high fuzzy similarity in function exponential decay and function decay constant satisfactory (Table 3). According to Novaes, et al. (2011) "indexes close to 0.4 indicate a good level of compatibility between the real and the simulated scenario", other studies make reference the values between 0.4 and 0.9, as Adams (2008) found that similarity values fuzzy between 0.83 and 0.85 in a simulation study in urban areas, Ferrari (2008) who obtained 0.44 and 0.84 for the dynamic simulation models for land use and land cover, and Benedetti (2010) which reached levels from 0.64 to 0.99 to work on simulation of forest development. The similarity indices for windows, obtained with the functions of exponential decay and decay constant, can be seen in Table 3.

Table 3. Scores of similarity of windows by function of exponential decay and function of decay constant for the simulations of 2002 and 2011.

	1991-2002		2002-2011	
Windows	**Exponential**	**Constant**	**Exponential**	**Constant**
3x3	0.643	0.752	0.586	0.679
5x5	0.688	0.861	0.657	0.833
7x7	0.702	0.906	0.682	0.908
9x9	0.708	0.934	0.690	0.939
11x11	0.710	0.952	0.692	0.958

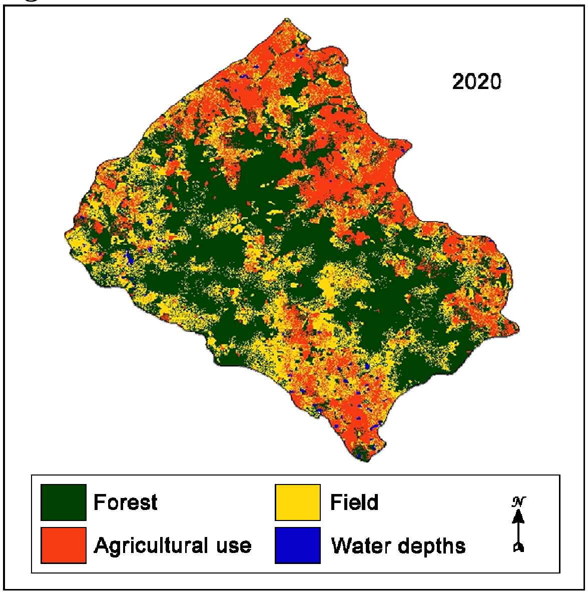
According to Ferrari (2008) the use of indexes by windows similarity in spatial simulation models is necessary because cannot reproduce past scenarios with spatial accuracy, but similarity indices based on fuzzy logic for not are based on only in cell by comparison cell, identifying the similarity of patterns (SOARES-FILHO; RODRIGUES; COSTA; 2009).

4.3 Simulation of future scenarios

The simulation of future scenarios is an important tool to aid in regional planning and environmental, because it provides important data on the dynamics of the landscape. The process of scenario modeling conducted in this study simulated the landscape of the micro-basin of the Arroyo Grande for the year 2020.

The generated model to perform the simulation algorithms for received "functors" Expander and Patcher same as those used in previous simulations of 2002 to 2011, average size of the patches as was used 3.6 h, and the variance of the patches 3.6 ha, and isometric equal to 1.6 (expander) and 1.5 (patcher). With the map of 2011 is used as initial map were established nine iterations. The simulation to 2020 can be seen in Figure 3, the values for each class hectare of use are shown in Table 4.

Figure 2. Simulation of the micro-basin of Arroyo Grande for the year 2020.



The simulation scenario for the year 2020 showed an increase in forest area (2.64%) and agricultural areas (4.38%), as well as a significant decrease in the areas of fields (-8.19%), the values of the areas of the classes are shown in table 4 and the evolution of use and cover 1991 to 2020 in the simulation graph of Figure 4.

Table 4. Total area of the simulated classes for 2020.

Class	Area 2020 (ha)
Forest	16954.11

Field	9143.37
Agricultural use	9031.59
Water depth	231.3

Figure 3. Chart the evolution of use and coverage of micro-basin of the Arroio Grande with the simulation for the year 2020.

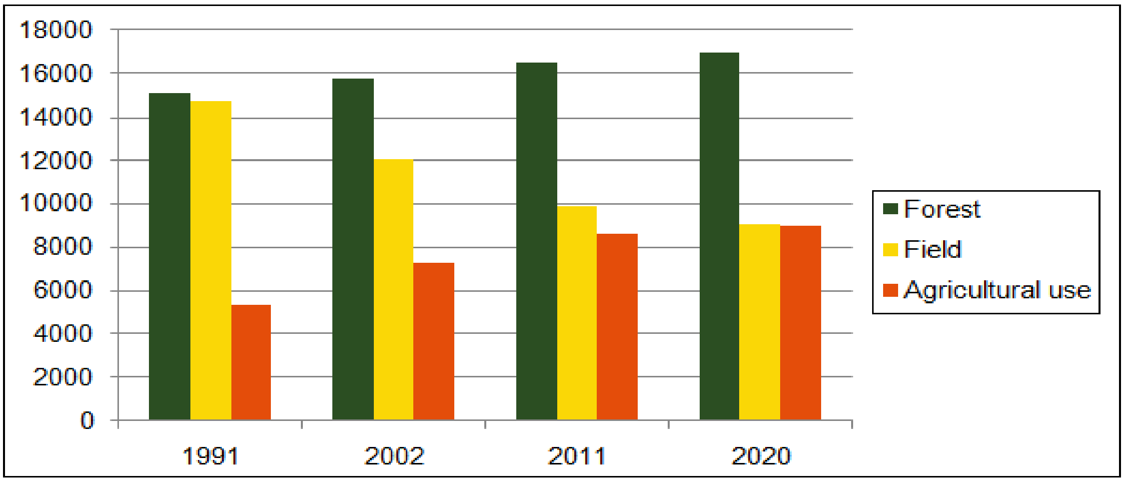


Table 5 presents a matrix of conversion between classes of use and coverage that occurred between 2011 and 2020 simulation.

Table 5. Conversion Class of 2011 to simulate the year 2020 (ha).

Of/To	Forest	Field	Agricultural use
Forest		1106.82	167.58
Field	1085.22		1942.56
Agricultural use	407.7	1512.72	

5. CONCLUSION

Dynamic models for simulating land use and land cover, as well as the use of platform Dinamica EGO, consists in very important tools for studies dedicated to the exploration of future scenarios. The results were very satisfactory in this article, the simulations for the years 2002 and 2011 reached similarity indices above 0.95%. The forecast scenario for the year 2020 showed little change compared with the percentage change from previous periods, indicating an increase of 2.64% in forest areas, 4.38% in the areas of agriculture and a decrease of 8.19% of the fields, this dynamic may indicate a tendency to stagnation in the areas of agriculture, because there are no major tracts of land suitable for the advancement of agriculture, the main driver of developments in the study period.

6. REFERENCES

ALMEIDA, C. M.; CAMARA, G.; MONTEIRO, A. M. V.; SOARES-FILHO, B. S.; CERQUEIRA, G. C. Modelos Celulares de Dinâmicas Espaço-Temporais: Aplicações em Estudos Urbanísticos. In: Margareth Simões Penello Meirelles; Gilberto Câmara Neto; Cláudia Maria de Almeida. (Org.). Geomática: Modelos e Aplicações Ambientais. 1 ed. Brasília: EMBRAPA, 2007, v. 1, p. 445-496.

ALMEIDA, C. M.; MONTEIRO, A. M. V.; CÂMARA, G.; SOARES-FILHO, B. S.; CERQUEIRA, G. C.; ARAÚJO, W. L.; PANTUZZO, A. E. Modeling the Urban Evolution of Land Use Transitions Using CA and Logistic Regression. [CD-ROM]. In: **Proceedings of the IEEE - International Geoscience and Remote Sensing Symposium**, Toulouse, v. 3, 2003, p. 1564-1566. Toulouse, France: CNES, 2003.

BAKER, W. L. A review of models of landscape change. **Landscape Ecology**, Amsterdã v. 2, n. 2, p. 111-133, 1989.

BENEDETTI, A. C. P. **Modelagem dinâmica para simulação de mudanças na cobertura florestal das Serras do Sudeste e Campanha Meridional do Rio Grande do Sul**. 2010. 166 f. Tese (Doutorado em Engenharia Florestal) – Universidade Federal de Santa Maria, Santa Maria, 2010.

BURROUGH, P. A.; McDONNEL, R. A. **Principles of Geographical Information Systems.** Oxford: Clarendon Press, 1998. 333p.

BRIASSOULIS, H. **Analysis of land use change: theoretical and modeling approaches.** 1.ed. Virginia: Regional Research Institute, West Virginia University, 2000.

DIEGUES, A. C. **Inventários de Áreas Úmidas do Brasil**: versão preliminar. Pró-Reitoria de Pesquisa da Universidade de São Paulo, União Internacional para Conservação da Natureza, Fundação Ford. São Paulo, 1990. 446 p.

DUARTE da Silva, P. A.; TAVARES. V. E. Q. **Preservação de Áreas Úmidas.** Rev. Bras. Agroecologia, v.2, n.1, fev., 2007.

FERRARI, R. **Modelagem Dinâmica do Uso e Cobertura da Terra da Quarta Colônia, RS**. 2008. 130f. Dissertação (Mestrado em Geomática) – Universidade Federal de Santa Maria, Santa Maria, 2008.

FERNANDEZ, P. J. **Introdução aos processos estocásticos**. INPA/CNPq, Rio de Janeiro. 1975. 139 p.

GARCIA; R. A.; SOARES-FILHO; B. S.; MORO; S. Modelagem Espacial do Desmatamento Amazônico**.** Trabalho apresentado no XIV Encontro Nacional de Estudos Populacionais, ABEP, realizado em Caxambú - MG – Brasil, de 20- 24 de Setembro de 2004. (2004)

GREMONINI, L.; VICENTINI, E. **Autômatos Celulares:** Revisão Bibliográfica e Exemplos de Implementações. Curitiba: UNICENTRO, 2008. Revista Eletrônica. Disponível em: http://web03.unicentro.br/especializacao/Revista_Pos/CE-Autom.pdf. Acesso em 02 ago. 2009.

HENDGES, E. R. **Modelos estocásticos da dinâmica da paisagem florestal e simulação de cenários para o Estado do Rio Grande do Sul no período de 1988 a 2020**. 2007. 233 f. Tese (Doutorado em Engenharia Florestal) – Universidade Federal de Santa Maria, Santa Maria, 2007.

ITAQUI, J. Quarta Colônia – Inventário Técnico de Flora e Fauna. Santa Maria: Condesus, 2002.

Joint Research Centre – European Commission - Institute for Remote Sensing Applications (JRC); European Space Agency – Earthnet Programme Office (ESAESRIN). **Modelling Deforestation Processes** – a review. Luxembourg: ECSC-ECEAEC, 1994. (Trees Series B, Research Report n.1).

KLEINPAUL, J. J. **Análise multitemporal da cobertura florestal da Microbacia do Arroio grande, Santa Maria, RS**. 80 f. Dissertação (Mestrado em Engenharia Florestal) – Universidade Federal de Santa Maria, Santa Maria, 2005.

LAMBIN, E. F. **Modelling deforestation processes**: a review. TREES series B: Research Report n1, European Commission, EUR 15744 EN. Office of Official Publications of the European Community, Luxembourg. 1994.

MAS, J. F. et al. Uma comparación de programas de modelación de cambios de cobertura/uso Del suelo. In: XV SBSR . Curitiba, 30 de abril a 05 de maio de 2011.

NASA – National Aeronautics and Space Administration. 2011. Disponível em: http://www.nasa.gov/. Acesso em: 10 set. 2011.
NOVAES, M. R. Análise da redução da queima na colheita da cana-de-açúcar por meio de modelagem dinâmica espacial. 253 f. Dissertação (Mestrado em Sensoriamento Remoto). Instituto Nacional de Pesquisas Espaciais, São José dos Campos-SP. 2010.

PEDROSA, B. M. **Ambiente Computacional para Modelagem Dinâmica Espacial**. 111 f. Tese (Doutorado em Computação Aplicada). Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2004.

PEDROSA, B. M.; CAMARA, G. Modelagem Dinâmica e Geoprocessamento. São Paulo: INPE, 2002. Disponível em <sid.inpe.br/Sergio/2004/10.07.15.07> Acesso em 24 de outubro de 2011.

PEREIRA, R. S.; BENEDETTI, A.C. P. ; ALMEIDA, C.M. de. Dynamic Modeling for Changes Simulations in the Forest Cover in Rio Grande do Sul State, Brazil. **Anais** FIG Working Week, Marrakech, Morocco, 18-22 May 2011 p.

ROCHA, J.; SOUSA, P. M; TENEDÓRIO, J. A. Geosimulação e Análise Espacial: Redes Neuronais e Autômatos Celulares na Previsão de Alterações nos Padrões de Uso e Ocupação do Solo**. Inforgeo**, Lisboa, v. 16, n. 17, p.123-137, 2001.

RUHOFF, A. L. Gerenciamento de Recursos Hídricos em Bacia Hidrográficas: Modelagem ambiental com a simulação de cenários preservacionistas. 93 f. Dissertação (Mestrado em Geomática) – Universidade Federal de Santa Maria, Santa Maria, 2004.

RUHOFF, A. L. et al. Modelagem Ambiental e dinâmica de uso e cobertura da terra na Bacia do Arroio Grande. **Anais** XII Simpósio Brasileiro de Sensoriamento Remoto, Goiânia, Brasil, 16-21 abril 2005, INPE, p. 3293-3300.

SERRATO, J. et al. Comparación del modelo markoviano y de regresión para predicción de cambios en el uso y cobertura del suelo en la zona central del Departamento del Meta-Colombia. **Anais** XV Simpósio Brasileiro de Sensoriamento Remoto, Curitiba, Brasil, 30 de abril a 05 de maio 2011, INPE, p. 6532-6529.

SKOLE, D. L. Data on global land-cover change: acquisition, assessment, and analysis**.** In: MEYER, B. W.; TURNER, L. B. (Org.). **Changes is Land Use and Land Cover: A Global Perspective.** Cambridge: Cambridge University Press, 1994. 537 p.

SOARES-FILHO, B. S. Modelagem da dinâmica de paisagem de uma região de fronteira de colonização amazônica. 299 f. Tese (Doutorado em Engenharia de Transportes) – Escola Politécnica da Universidade de São Paulo, 1998.

SOARES-FILHO, B. S. DINAMICA – Um software para simulação de dinâmica de paisagens. **Anais do II Workshop em Tratamento de Imagens, NPDI/DCC/UFMG**, 2001.

SOARES-FILHO, B. S.; CERQUEIRA, G.C; ARAUJO, W. L.; VOLL, E. **Modelagem de dinâmica de paisagem: concepção e potencial de aplicação de modelos de simulação baseados em autômato celular.** In: ALBERNAZ, A. L.; SILVA, J. M. C. da; VALERIANO, D. (editores) Ferramentas para modelagem da distribuição de espécies em ambientes tropicais (no prelo). Belém: Editora Museu Paraense Emílio Goeldi, 2004.

SOARES-FILHO, B. S.; RODRIGUES, H. O.; COSTA, W. L. **Modelagem de Dinâmica Ambiental com Dinamica EGO**. Centro de Sensoriamento Remoto/Universidade Federal de Minas Gerais. Belo Horizonte, Brazil, 2009.

RODRIGUES, O. H.; SOARES-FILHO, B. S.; COSTA, W. L. de S. **Dinamica EGO, uma plataforma para modelagem de sistemas ambientais.** Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril 2007, INPE, p. 3089-3096.

SOARES-FILHO, B.S., PENNACHIN, C.; CERQUEIRA, G. DINAMICA – a stochastic cellular automata model designed to simulate the landscape dynamics in Amazonian colonization frontier. **Ecological Modelling**, v.154, p. 217-234, 2002.

TORRES, D. R. Análise multitemporal do uso da terra e cobertura florestal com dados dos satélites Landsat e ALOS. 96 f. Dissertação (Mestrado em Engenharia Florestal) – Universidade Federal de Santa Maria, Santa Maria, 2011.

VELDKAMP, A.; LAMBLIN, E.F. Agriculture, Ecosystems and Environment. Predicting land-use change. **Agriculture, Ecosystems and Environment**, v. 85, p.1-6, 2001.

White, R., G. Engelen, and I. Uljee. 2000. "Modeling Land use Change with Linked Cellular Automata and Socio-economic Models: A Tool for Exploring the Impact of Climate Change on the Island of St. Lucia". Pp. 189-204 in: M. Hill and R. Aspinall (eds.), Spatial Information for Land Use Management, Gordon and Breach, Newark, New Jersey, U.S.A.