Forecast Models of Urban Growth and Land Use Change to Assess Human Vulnerability Resulting from Threats to Water Resources

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Abstract

Models for the simulation of urban land use change have continuously undergone refinements in the latest decades, what rendered them powerful tools to support decision-making, policy making and initiatives in the realm of town planning. They may meet the most diverse ends, such as the monitoring and control of urban growth, evaluation of infrastructure investment needs, identification of conflicts between urban expansion and site suitability, amongst others. This paper is committed to present a simulation model of urban land use change for the town of Bauru, located in the central west of São Paulo State, Brazil. The thereof generated forecasts indicate how the uncontrolled urban growth may represent serious risks to the water spring of the town and provide thus subsidies for assessing the human dimensions of the vulnerability resulting from threats to water resources due to processes of land use change taking place in the urban fringe of Bauru.

1. Introduction: Historical Perspective on Models of Urban Growth and Land Use Change

1.1 Concepts and Definitions on Land Use Change and Modeling

Various are the definitions for the terms land, land use and land use change, and they vary according to the purpose of application and the context of their use. Wolman (1987) cites Stewart´s (1968) definition of land in the scope of natural sciences: "the term land is used in a comprehensive, integrating sense … to refer to a wide array of natural resource attributes in a profile from the atmosphere above the surface down to some meters below the land surface. The main natural resource attributes are climate, land form, soil, vegetation, fauna and water."

In a more economical approach, Hoover and Giarratani (1984) state that land "first and foremost denotes space … The qualities of land include, in addition, such attributes as the topographic, structural, agricultural and mineral properties of the site; the climate; the availability of clean air and water; and finally, a host of immediate environmental characteristics such as quiet, privacy, aesthetic appearance, and so on."

Land use, on its turn, denotes the human employment of land (Turner and Meyer, 1994). FAO/IIASA (1993) states that "land use concerns the function or purpose for which the land is used by the local human population and can be defined as the human activities which are directly related to land, making use of its resources or having an impact on them."

According to Briassoulis (2000), land use change "… means quantitative changes in the areal extent (increases or decreases) of a given type of land use…". For Jones and Clark (1997), it may involve either a) conversion of one type of use into another or b) modification of a certain type of land use, such as changes from high-income to low-income residential areas (the buildings remaining physically and quantitatively unaltered).

As to the particular term "model", it can be understood as the representation of a system, which can be achieved through different languages: mathematical, logical, physical, iconic, graphical, etc., and according to one or more theories (Novaes, 1981).

A system is a set of parts, presenting interdependence among its constituent components and attributes (Chadwick, 1973). A theory, on its turn, can be defined as a set of connected statements which, through logical constructs, supplies an explanation of a process, behavior, or other phenomenon of interest as it exists in reality (Chapin and Kaiser, 1979; Johnston et al. 1994).

In a general way, models can be basically classified according to the following typologies (Echenique, 1968; Novaes, 1981):

- *descriptive model*: it aims at solely understanding the functioning of a system;

- *explorative model*: it is a descriptive model that involves the parametric analyses of several states, by means of variations in the systems elements and their relations, with no external interference upon it. These kind of models are meant for answering "what if" questions;

- *predictive model*: it is an explorative model that involves the time variable, comprising the projection of some basic elements;

- *operational model*: it renders available the interference of the modeler, who can introduce exogenous factors in the system components and relations in a way to modify its behavior[1].

According to Batty, Popper´s concept of science as "a process of conjecture, then refutation of problems, followed by tentative solutions, error-elimination and the redefinition of problems (Batty, 1976 citing Popper, 1972)" is reflected in the development of urban theories and models.

1.2 Evolutionary Overview on Urban Land Use Change Models

Theoretical and mathematical models have for long been created for purposes of urban studies, aiming at clarifying processes of urban and regional change. One of the oldest contributions in this sense is Von Thünen´s theory of concentric rings, dated back to 1826. According to his rent-locational model, the most intensive use of land will be near the center, and the rent or land values will decrease outwards (Perraton and Baxter, 1974).

Other similar approaches in economic theory is the classical triangle of industrial location proposed by Weber in 1909, Christaller´s model of central places of 1933, and Lösch´s theory of economic regions, developed in 1940 (Merlin, 1973; Perraton and Baxter, 1974).

[1] A branch of operational models would be the prescriptive or normative models, which attempt to change the system under analysis in some optimal way.

Following these simple economic-oriented achievements in urban modeling, a new generation of computerized urban models came into play in the late 1950s and early 1960s, (Alonso, 1960; Lowry, 1964) immediately following the advances in computational facilities at that time and the advent of the Quantitative Revolution. Important drawbacks of these early models concern their oversize, arbitrary and mechanistic structure and the fact that they could only describe the urban structure at one cross-section in time, or at best, compare these static structures incorporating some long-term and often imputed equilibrium, what rendered them mere simulations of the static observable structure of cities (Batty, 1976).

In an effort to overcome the shortcomings of the first generation urban models, a new bunch of modeling accomplishments commits itself, amongst other things, to work on a dynamic basis (Crecine, 1964; Hill, 1965; Paelinck, 1970), i.e. to present an explicit time dimension, where inputs and outputs vary over time (Wegener et al., 1986). Even though considerable refinements were introduced in this early generation of dynamic models in terms of coping with the complex and sometimes recursive spatial interactions among different activities in a city, of adding the (multi-level) time dimension in the quantitative analyses and employing sophisticated mathematical and theoretical tools - e.g. differential equations (Allen et al., 1981), these models remained fairly non-spatial, especially in the sense that their results could not be spatially visualized.

In brief, the urban models developed from the 1950s until the mid 1980s, in a fairly general sense, did not take the spatial dimension into account. When this happened, the urban space was decoupled into units (usually zones defined according to trip generation, census districts or other alike criteria), but the output of such models could not be spatially handled. In fact, effective advances in the spatial representation of urban models occurred only by the end of the 1980s, when cellular automata (CA) models started to be largely applied, also impelled by the parallel development in computer graphics and in theoretical branches of complexity, chaos, fractals and alike (Batty et al. 1997).

Stephen Wolfram, one of the most renowned theoreticians on cellular automata defines them as: "…mathematical idealizations of physical systems in which space and time are discrete, and physical quantities take on a finite set of discrete values. A cellular automaton consists of a regular uniform lattice (or `array´ ), usually infinite in extent, with a discrete variable at each site (`cell´). The variables at each site are updated simultaneously (`synchronously´ ), based on the values of the variables in their neighborhood at the preceding time step, and according to a definite set of `local rules´ (Wolfram, 1983, p. 603)".

Cellular automata (CA) models have found applications in diverse fields, ranging from statistical and theoretical physics to land use and land cover change, traffic engineering and control, diseases spread, behavioral biology, amongst others.

The 1990s experienced successive improvements in urban CA models, which started to incorporate environmental, socioeconomic and political dimensions (Phipps and Langlois, 1997), and were finally successful in articulating analysis factors of spatial micro and macroscale (White et al., 1998). Leading theoretical progresses in the broader discipline of artificial intelligence (AI), such as expert systems, artificial neural networks and evolutionary computation, have been lately included in the scope of CA simulations. As stated in Almeida et al. (2003), methods recently embedded in CA models like those employing contemporary pattern-fitting tools such as neural nets (Wu, 1998; Yeh and Li, 2001) and evolutionary learning (Papini et al. 1998) are revealing to be amongst the most promising for the coming generation of urban CA modeling achievements.

2. A Case Study: Simulation and Forecasts of Urban Growth and Land Use Change in the City of Bauru, SP, Brazil by Means of a CA Model

2.1 Study Area

Bauru is considered the biggest crossing point among railways, waterway and highways in Latin America. The city itself was born as a crossing point between railways during the inward advance of the coffee culture in the XIX century. Still today, the city is mainly shaped by the transport system: its urban framework is organized around four interregional roads and the railway track, which still crosses the city core area.

Bauru is currently regarded as a dynamic regional development pole in the central-west portion of São Paulo State, with an outstanding performance of tertiary activities (commerce and services). In view of its strategic historic development conditions, the city underwent a drastically fast urbanization process. These urbanization booms were followed by speculative processes, leading to the formation of a discontinuous urban fabric, marked by the scattered presence of empty areas, high-rise buildings in the central neighborhoods (FIGURE 1), low occupation densities in the outer areas, and the existence of detached predominantly low-income residential settlements orbiting around the city center.

FIGURE 1 – Bauru aerial view with high-rise buildings.
SOURCE: ITE-FCEB (1998).

2.2 Simulation Model of Urban Land Use Change: 1967 - 2000

In order to carry out modeling experiments designed to generate forecasts of urban land use change, it is necessary at first to get acquainted with the driving forces or variables governing land use change throughout a sufficiently long time series. These variables concern infra-structural and socio-economic aspects of the city under analysis. In the particular case of this experiment, the simulation time interval ranged from 1967 to 2000, comprising thirty-three years, in which the urban population increased about 500%, rising from 61,592 to 310,442 inhabitants. The acquired knowledge with respect to the variables role in delineating the spatial patterns of land use change must support the parameterization of the forecast models, which represent the ultimate goal of modeling.

2.2.1 Exploratory Analysis and Variables Selection

The exploratory analysis consists in the initial stage of modeling, where a series of procedures is executed aiming to evaluate the characteristics of the variables driving land use change. This enables the choice of the minimum and at the same time the best set of variables to explain a certain type of transition (e.g. from non-urban use to residential use). The exploratory analysis as well as all the remaining stages of the modeling process are accomplished for each consecutive simulation period. In the case of Bauru, these periods were delimited according to the availability of official land use maps. As these maps were released only in 1967, 1979, 1988, and 2000, the simulation time series contained three periods: 1967-1979; 1979-1988 and 1988-2000.

Initially, the process of variables selection is based on a heuristic procedure, where maps of variables are superimposed on the final land use map in vector format for the considered simulation period (FIGURE 2), in a way to identify those more meaningful to explain the different types of land use change.

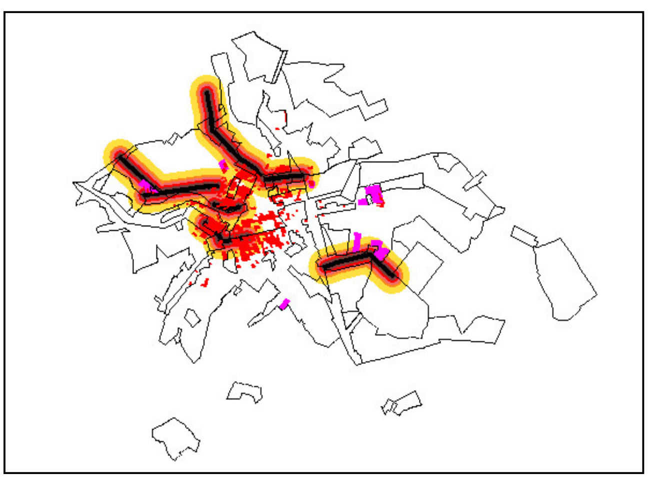

FIGURE 2 – Illustrative image showing the visual analysis for the identification of variables determining the transition from residential to mixed use in Bauru from 1979 to 1988. The buffers are distances to planned roads; the red spots are areas of medium-high density; and the pink polygons correspond to social housing.

In order to avoid redundancy in the input data, i.e. select variables with a high degree of spatial dependence or association, the variables underwent pair-wise statistical tests, like the Cramer´ s Index and the Joint Information Uncertainty, with the acceptable threshold set to 0.5 (Bonham-Carter, 1994). When this value is surpassed, the variables can be combined into one, or one of the two has to be discarded. In a general way, the variable that presents the smallest spatial association with the considered land use transition, i.e. the one which contributes less to explain the transition at issue is eliminated from the model.

2.2.2 Model Parameterization

Models for the simulation of urban land use change are commonly built upon basis of empirical methods. In the case study here presented, the "weights of evidence" method has been adopted, which is based on the Bayes´ s theorem of conditional probability. This theorem consists in ratios relating the areas of occurrence of certain variables to the areas where the phenomena under study have taken place (land use transitions). In this way, for each cell of the study area, the probability that a given type of land use change will happen in face of the previous occurrence of certain variables is:

$$P_{x,y}\{R/S_1 \cap S_2 \cap \ldots S_n\} = \frac{O\{R\} \cdot e^{\sum_{i=1}^{n} W^+_{x,y}}}{1 + O\{R\} \cdot \sum_{j=1}^{t} e^{\sum_{i=1}^{n} W^+_{x,y}}}, \qquad (1)$$

where $P_{x,y}$ corresponds to the probability of a cell with coordinates x,y to undergo a land use transition R (e.g. from non-urban to residential use); S_{1-n} refer to the n variables (or evidences) driving land use change; $O\{R\}$ corresponds to the *odds* of R, which is the ratio of the probability of occurring R ($P\{R\}$) to its complementary probability ($P\{\overline{R}\}$); and W^+ represents the positive weight of evidence, which is calculated through the statistical method "weights of evidence" (Bonham -Carter, 1994), and indicates the attraction or positive correlation between a certain evidence and a given land use transition.

2.2.3 Model Calibration

Likewise in the exploratory analysis, heuristic procedures were employed for the model adjustment or calibration. Visual comparative analyses were conducted for each type of land use change, considering preliminary simulation results, maps of land use transition and of transition probabilities as well as the overlay of maps of variables upon the final land use map in vector format. This comparison envisages identifying those variables or evidences which are effectively concurring to explain the respective transitions from those which are just noise in the modeling, and it has been employed for both the variables selection and the definition of the internal parameters of the simulation software- DINAMICA[2].

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[2] DINAMICA is a cellular automata model for the simulation of landscape dynamics (land use and land cover change), developed by the Center for Remote Sensing of the Federal University of Minas Gerais (http://www.csr.ufmg.br). The sofware was written in object-oriented C++ language, and its present version runs on 32 bit Windows © system (Soares-Filho et al., 2002).

2.2.4 Simulation and Results

Several simulations were carried out by the DINAMICA model, and the best results for each simulation period are presented in FIGURE 3. Upon basis of the carried out calibration process, it becomes evident that the probability of certain non-urban areas in the city of Bauru to shelter residential settlements largely depends on the previous existence of this type of settlements in their surroundings, because this implies the possibility of extending existing nearby infrastructure. It also depends on the greater proximity of these areas to commercial activities clusters and on the available accessibility to such areas.

As to the transition of non-urban areas to industrial use, there are three great driving forces: the nearness of such areas to the previously existent industrial use and the availability of road and railway access. This can be explained by the fact that in the industrial production process, the output of certain industries represent the input of other ones, what raises the need of rationalization and optimization of costs by the clustering of plants interrelated in the same productive chain. Furthermore, plots in the vicinities of industrial areas are often prone to be devaluated for other uses, what makes them rather competitive for the industrial use.

Regarding the transition of non-urban areas to services use, three major factors are crucial: the proximity of these areas to clusters of commercial activities, their closeness to areas of residential use, and last but not least, their strategic location in relation to the main urban roads of Bauru. The first factor accounts for the suppliers market (and in some cases also consumers market) of services; the second factor represents the consumers market itself; and the third and last factor corresponds to the accessibility for both markets related to the services use.

The creation of leisure and recreation zones, on its turn, takes place in outer areas with good accessibility, and sometimes along low and flat riverbanks, since these areas are floodable and hence unsuitable for sheltering other urban uses.

And finally, the transition from residential use to mixed use[3] supposes the availability of water supply and the existence of good accessibility conditions. These areas also strive for locating not too far away from central commercial areas, for they depend on the specialized supply from these areas, but not too close to them either for competitiveness reasons.

It is worth stating that the natural characteristics of the physical environment have not been considered as impedances to urban land use change and growth at a more generalized level, since the city site is relatively flat, with mild slopes, and presents no outstanding condition regarding soil, vegetation and conservation areas constraints.

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[3] The mixed use zone basically comprises the residential, commercial, and services use. These zones actually play the role of urban sub-centers and represent a sort of secondary commercial centers enhancement, which at a later stage start to attract services and social infrastructure equipments besides commercial activities themselves.

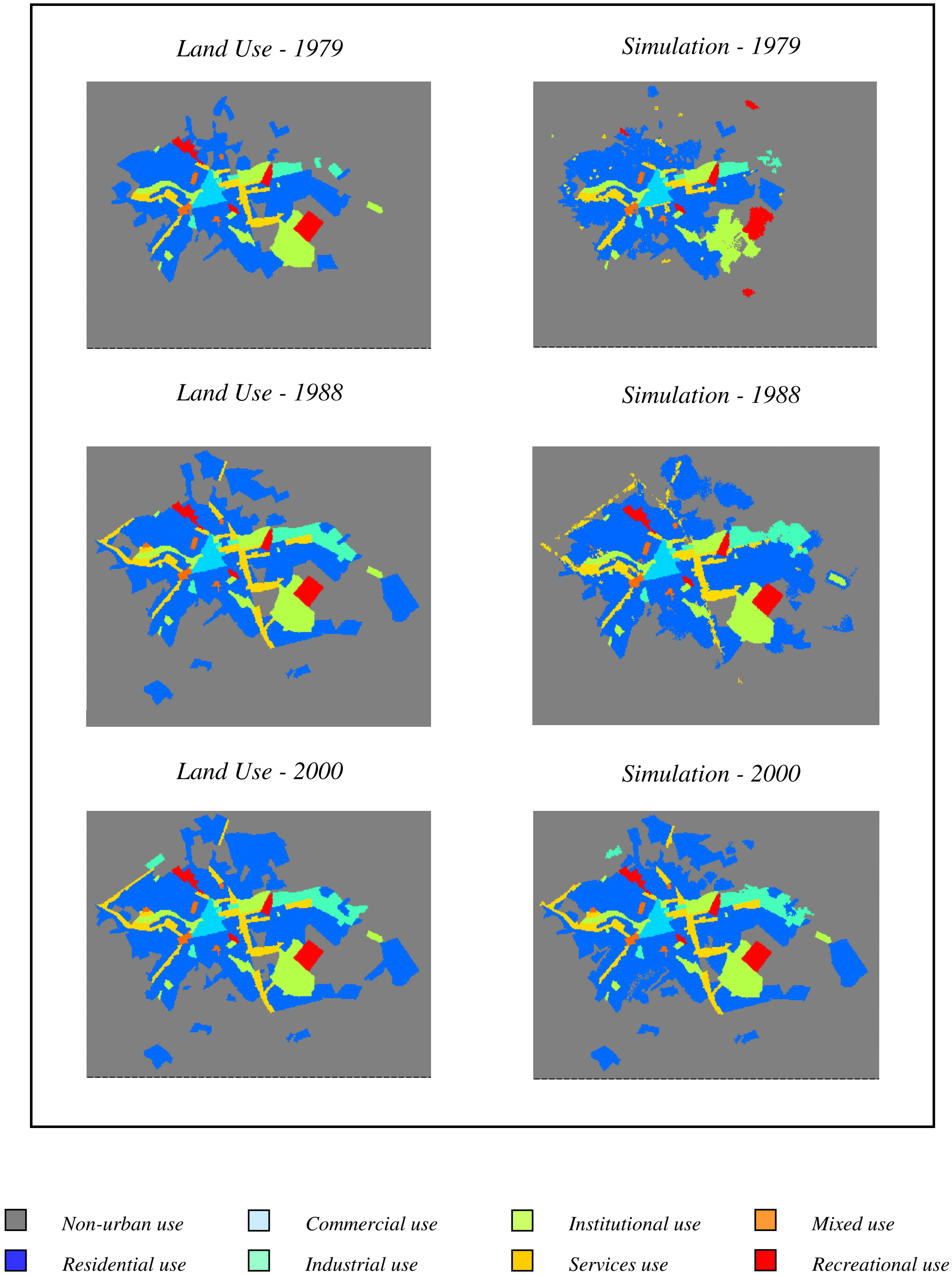

FIGURE 3 – Real land use and respective simulations for Bauru in the years 1979, 1988, and 2000.

2.2.5 Model Validation

In order to evaluate the model performance, a method based on multiple resolutions has been employed (Constanza, 1989), where the ` goodnessof-fit´ between the real and the simulated image is assessed not on a pixel-per-pixel basis but rather by means of sampling windows of different sizes, relaxing thus the rigidity of adjustment between reality and simulations. For the first simulation period (1967-1979), the fit index ranged from 0.941 to 0.944; for the second period (1979-1988), from 0.896 to 0.903, and finally for the third period (1988-2000), from 0.954 to 0.957.

2.3 Forecast Model of Urban Land Use Change: 2000 - 2007

With the knowledge on transition trends and patterns acquired by means of the simulation experiments executed throughout sufficiently long time series, it is then possible to generate forecasts scenarios of urban land use change. For purposes of simplification, this study considers only three types of scenarios: a stationary one, which preserves the transition trends observed in the most recent simulation period; an optimistic one, which slightly overestimates these trends; and a pessimist scenario, which slightly underestimates such trends.

In models designed to simulate land use change, there are two types of transition probabilities: one global, which estimates the total amount of change for the study area, regardless of the influence imposed by the respective variables; and a local one, calculated for each cell taking into account such variables. In the generation of forecast scenarios, the global probabilities are recalculated, whereas the values of the local transition probabilities remain the same. In the case of stationary scenarios, the Markov chain is employed to reckon the global transition probabilities, which consists in a mathematical model meant to describe a certain type of process that moves in a sequence of steps and throughout a set of states.

For the non-stationary scenarios, univariate linear regression models were adopted, where the area of a certain type of land use in 2007 (dependent variable) is explained by means of a demographic or economic indicator (independent variable), such as urban population or local industrial GDP. As previously mentioned, upon basis of slight over and underestimations of these indicators, optimistic and pessimist global transition probabilities are respectively calculated. Different results of forecast scenarios for the year 2007 are shown in FIGURE 4.

It is worth mentioning that the scenarios point to the maintenance of the ongoing trend of peripheral residential settlements, which underutilize the infrastructure network and hence raise the costs of infrastructure investments in face of their scattered occupation pattern (SEPLAN, 1997). Another observed tendency indicated by the forecasts is the strengthening of the urban expansion towards the southwest side of the town, exactly where the spring for the city water supply is located. In this way, the current urban policies and initiatives must immediately envisage efficient devices to inhibit such typologies of urban expansion.

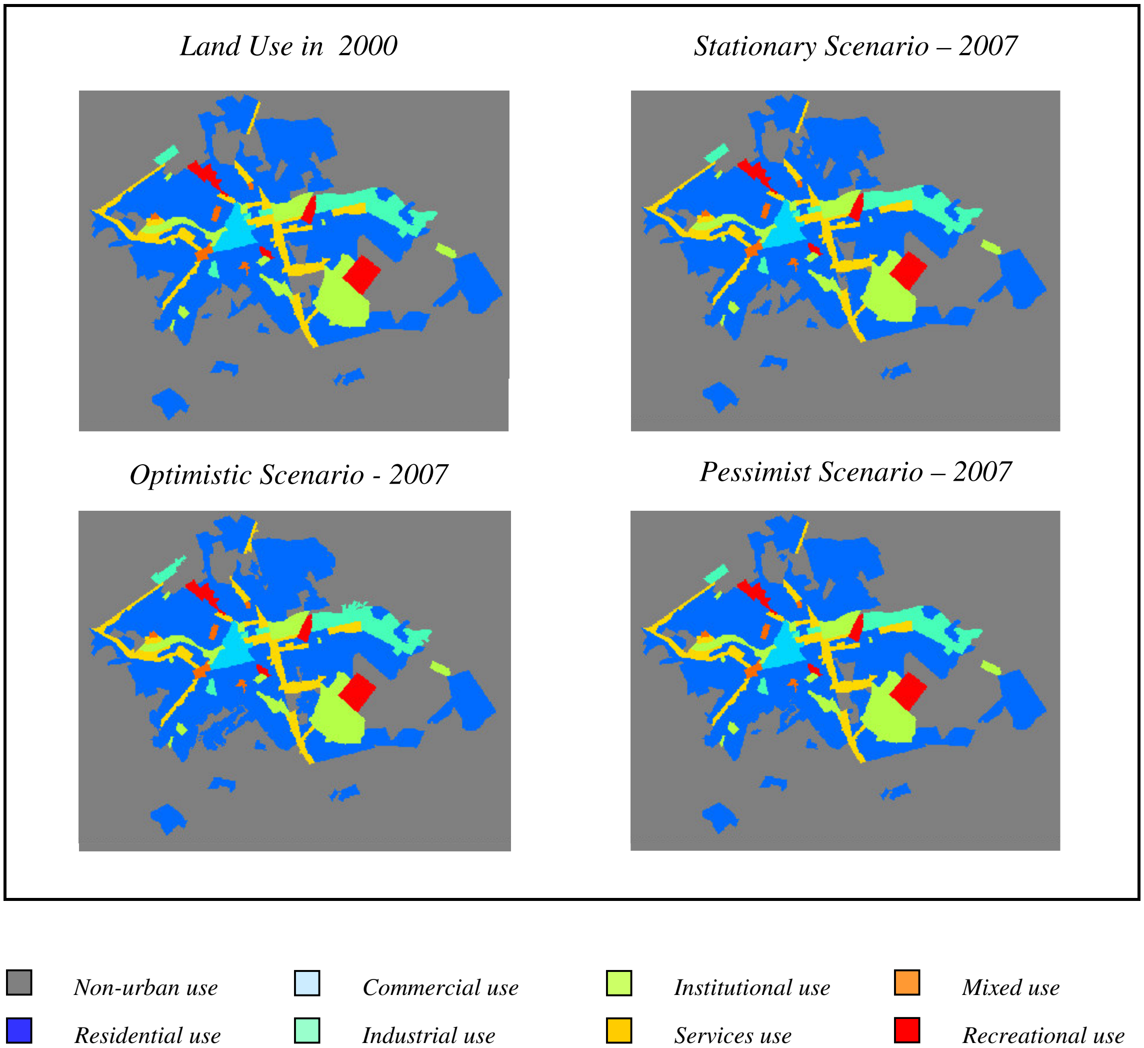

FIGURE 4 – Stationary, optimistic and pessimist scenarios for 2007 and real land use in 2000 - Bauru.

3. Human Dimensions of the Vulnerability Resulting from Threats to Water Resources due to Processes of Urban Land Use Change in the Urban Area of Bauru, SP, Brazil

3.1 Agents Driving Urban Land Use Change: Profile and Behavior

Changes caused in the urban scenario are impelled by diverse agents or social actors. Enterpreneurs dedicated to services and commercial activities strive to optimize locational advantages in the urban area of Bauru. They tend to settle close to main roads, not only because of the need of an efficient accessibility to goods and clients, but also due to the fact that these roads grant visibility to their businesses, attracting potential new clients.

Similarly, industrial plants also struggle for competitive sites, taking into account land price, good acessibility conditions for the supply of raw material and output delivery as well as the warranty of rationalization in the production process in view of the proximity to other plants interrelated within the same productive chain.

Leisure and recreation zones, built and managed by local authorities, rely in terms of locational choice on site amenities, like landscape assets and good accessibility conditions, since the latter are crucial for the survival of such areas.

Peripheral residential areas are meant either for low-income or high-income dwellers. High-income settlements tend to be detached from the main urban agglomeration for purposes of larger plots, usually unavailable within the city fabric, and access to pleasant landscapes. In the specific case of Bauru, there is only one high-income settlement isolated from the main urban agglomeration, located to the east of the town. This type of settlements usually observes legal environmental restrictions.

Peripheral low-income settlements usually correspond to spontaneous initiatives of poor inhabitants or to informal undertakings carried out by ilegal land state enterpreneurs. These settlements are commonly situated away from the main urban agglomeration due to the reduced land prices. New peripheral settlements tend to be located close to previous ones, because this implies the possibility of extending existing nearby infrastructure, such as water supply, bus lines, public lighting, electric energy supply, etc. They also seek to be near main acess roads, since this refers to the dwellers´ need of commuting to work places and shops in central areas. Contrarily to high-income settlements, low standard settlements commonly disregard environmental constraints, and not rarely take place in conservation areas, like natural parks, forest reserves or water springs protection areas.

It becomes thus evident that the agents of land use change in the city of Bauru comply with the logics of economic theories of urban growth and change, grounded on the key concept of utility maximization (Papageorgiou and Pines, 2001; Zhou and Vertinsky, 2001), in which there is a continuous search for optimal location, able to assure:

- competitive real estate prices;
- good accessibility conditions;
- rationalization of transportation costs, and
- a strategic location in relation to suppliers and consumers markets.

3.2 Impacts of Uncontrolled Urban Growth in the Vicinities of Water Springs on Liveability and Human Health

Informal land occupation in areas of water springs protection impacts not only the ecological balance of the natural environment but also brings about damages to the quality of life of urban inhabitants who directly depend on such supply sources. The foremost observed effects of informal settlements located in the surroundings of water springs are:

- direct discharge of sewage into the water bodies;

- destruction of riparian vegetation;
- silting of water reservoirs;
- floods;
- disturbances in the hydrological balance of the region;
- contamination of water resources;
- and, consequently, shortage of water supply.

Considering that a reliable access to fresh water is a key component of `quality of life´, it is sensible to state that uncontrolled urban expansion in the proximities of water sources represents a serious threat to liveability, and ultimately, to human health not only of the informal settlements dwellers, but also of the city´s inhabitants as a whole.

The term `quality of life´ is intertwined with the concept of `liveability´, which can be briefly described as unique combinations of amenity values (open space, urban vegetation, ecological services); historic and cultural heritage; location; and intangibles such as character, landscape and `sense of place´ (Bell, 2000). Liveability very much concerns a `here and now´ perspective and basically refers to "the things that people see when they walk out the front door. While it is *about* the environment, it is not explicitly *for* the environment" (Brook Lyndhurst Ltd., 2004).

Most of the consequences listed above directly impact liveability, like the occurrence of floods, the unpleasant smell which might blow from the reservoirs, the undesirable visual effect of depleted riparian vegetation and contaminated waters as well as breakages and oscillations in the water supply. The spread of informal urban occupation in the vicinities of water springs and the consequent discharge of waste water directly into them cause a much more serious impact in human health, rendering both the communities living on the springs margins (which collect untreated water from such reservoirs) and the inhabitants dependent on this source supply vulnerable to infecto-contagious diseases, such as cholera, diarrhea, hepatitis in its diverse forms, leptospirosis, and schistosomiasis, amongst others.

3.3 Some Considerations on Human Dimensions of the Vulnerability to Environmental Changes

As stated by Hamza and Zetter (1998), "concentration of people and activities on safe sites is not a source of vulnerability. But the unequal distribution of resources, the marginalization of segments of the population and informal activities, and their exclusion from planned and serviced areas is what forces people on unsafe sites; and then vulnerability is a consequence". This opinion finds support in Watts and Bohle´s argument, which says that vulnerability is the "outcome between environmental and socio-economic forces" (Watts and Bohle, 1993).

Vulnerability is also defined as "insecurity and sensitivity in the well-being of individuals, households and communities in the face of a changing environment, and implicit in this their responsiveness and resilience to risks that they face during such negative changes. Environmental changes that threaten welfare can be ecological, economic, social and political, and they can take the form of sudden schocks, long-term trends or seasonal cycles" (Moser, 1998).

As exposed by Blaikie and Brookfield (1987) and by Bayliss-Smith (1991), any definition requires the identification of two dimensions of vulnerability: its *sensitivity* (magnitude of a system´ s response to an external event) and its *resilience* (the ease and rapidity of a system´ s recovery from stress From the point of view of the human dimensions of vulnerability, these two dimensions are closely interrelated to the economic, social, institutional, educational and psychological skills of individuals, households and communities to offer responsiveness and recovery capacity in face of stress or hardship.

In the particular case of the vulnerability resulting from threats to water resources in Bauru, sensitivity and resilience should be jointly offered by the dwellers and local authorities. As adaptive/mitigation measures to tackle the occurrence of breakages/fluctuations in the water supply and the risk of infecto-contagious diseases, the following are worth mentioning:

- spontaneous or induced relocation of squatters, with public assistance in both cases;
- implementation of sewerage systems in all legalized low-income settlements located in the water spring protection areas;
- creation of a permanent framework for water quality control and emergency management, supported by the local civil defence, envisaging immediate access to alternative supply sources, like aquifers and water import from neighboring watersheds;
- launching of environmental awareness campaigns concerning the importance of the water resources conservation in the mass media and in public and private schools.

And preventive public initiatives and actions to refrain the undesired urban sprawl in the vicinities of the water spring would include severe legal restrictions to the approval of new settlements; permanent inspection of spring protection areas; creation of anonymous denouncement channels to alert the public authorities about the eventual mushrooming of new informal settlements seeds; fiscal and institutional incentives for the implementation of low-income settlements in the eastern and northern sectors of the city, since the spring is located in the southwest side of the town; and finally, the construction of polarizing undertakings in the eastern and northern portions of Bauru, such as malls, business centers, thematic parks, in order to redirect urban expansion towards more environmentally suitable areas.

In fact, forecast models of urban growth and land use change lie in the realm of auxiliary tools to guide and support preventive measures meant to assure safe, comfortable and environmentally sound conditions in the urban life scope. These models are thus designed to anticipate risks and vulnerability circumstances, and accordingly, avoid or soften their extent and/or gravity.

4. Final Remarks and Directions for Future Work

According to Almeida et al. (2003), "cellular automata (CA) models have become popular largely because they are tractable, generate a dynamics which can replicate traditional processes of change through diffusion, but contain enough complexity to simulate surprising and novel change as reflected in emergent phenomena. CA models are flexible in that they provide a framework which is not overburdened with theoretical assumptions, and which is applicable to space represented as a raster or grid. These models can thus be directly connected to raster data surfaces used in proprietary geographic information systems".

Although urban dynamic models have been the target of severe criticism, mainly in view of their reductionism and constraints to fully capture the inherent complexity of reality (Briassoulis, 2000), it can be argued that they ought to exist, for they offer an incomparable way of abstracting patterns, order, and main trends of real world dynamics.

Actually, these models should be conceived, handled, applied, and interpreted in a wise and critical form, so that modelers, planners, public and private decision-makers as well as citizens in a general way could take the best from what they can offer and sensibly acknowledge their limits.

Such urban land use dynamics models demonstrate to be useful for the identification of main urban growth vectors and their predominant land use trends, what enables local planning authorities to manage and reorganize (if applicable) city growth according to the environmental carrying capacity of concerned sites and to their present and foreseen infrastructure availability. It is worth strengthening that the modeling forecasts presented in this work focused on water springs, but forecast models of urban growth and land use change can cope with any sort of threat to environmental resources produced by urban expansion processes.

And as final words, Batty concisely exposes the key ideas lying behind the applications and purposes of urban modelling when he says: "... There are many reasons for the development of such models: their role to help scientists to understand urban phenomena through analysis and experiment represents a traditional goal of science, yet urban modelling is equally important in helping planners, politicians and the community to predict, prescribe and invent the urban future (Batty, 1976, p. xx)."

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