Using an Urban Growth Simulator for Ensenada City Public Policy Analysis

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Abstract. Due to the complex nature of cities, it is necessary to have tools that help us understand them and anticipate unwanted futures. Such tools could be of great help to stakeholders and decision makers in the public policy design process regarding urban development. In 2010 the Municipal Institute of Research and Planning of Ensenada, Mexico, adapted a simulation software called Urban Growth Simulator to its own planning needs and test it to see what could be the impact of urban growth over agricultural land of the city. Then in 2014 results from a computational simulation model where included for the first time in a legal planning document that, once published on the state gazette, will be mandatory for all public officials. This work explains the general simulation process used in this exercise, its results, and ends with a reflection of the strengths and weaknesses of its use.

Keywords: Ensenada City, Modelling and Simulation, Urban Growth, Public Policies

1 Introduction

Ensenada is a 133-year-old Mexican coastal city with 350,000 inhabitants living in an urban area roughly 9,000 hectares facing challenges due to its abrupt topography, high land values, important natural areas, vast agricultural land, and two seaports; located just 100 km of the USA-Mexico border. This proximity translates in a higher car rate than other Mexican cities farther from the border of 1.8 inhabitants per car [9], its predominantly horizontal with a low density of 36 inhabitants per hectare and 10% of its urban surface are vacant lots. Because all of the above, Ensenada has faced a set of urban challenges that have been tackled with official urban planning programs with varied results.

1.1 Ensenada's first planning efforts.

Similar to what has been happening on a national level regarding urban planning, its application trough public policies had a recent and slow start in Ensenada but rapidly gain more importance in the past decade since the formation of the public planning agency (Municipal Institute of Research and Planning of Ensenada or IMIP in Spanish). From 2005 to 2015, 7 major official planning instruments have been elaborated [8–14] in comparison with only 3 [20–22] in the previous 30 years. Nonetheless, in retrospective it has been seen that the main urban problems of Ensenada have prevailed all this time in a reality where both economic and human resources are scarce for the implementation of this programs and municipal governments plan their activities within a three-year scope. In most recent efforts, the necessity to have a more focused, practical and informed way of planning has been made obvious.

1.2 The Value of simulation

Taking advantage of the ever increasing urban database of Ensenada and acknowledging recent computational methodologies regarding the study of cities, is that the IMIP has started integrating the urban simulation approach to improve its own planning processes trough what has been stated as two of the main uses of simulation: knowledge acquisition of the system under study and prediction of its behavior [5], thus making better informed decisions along the public policy design process, and testing them in a computational model before their real implementation to see what could happen.

2 The Urban Growth Simulator

2.1 Background

In 2010 the IMIP adapted the source code of a software called Urban Growth Simulator (UGS), designed by Kent State University and funded by the Environmental Protection Agency. It was originally conceived to develop a way for interested community groups and citizens to interactively generate build out scenarios so that the impacts on the environment caused by urban sprawl could be observed [17]. In that year a simulation exercise was used to evaluate the impacts of urban growth over an agricultural valley of Ensenada [23], obtaining relevant results regarding the impact that surrounding areas could have if strict growth policies where implemented in the valley. Then, in 2014 results from a computational simulation model where included for the first time in a legal planning document that, once published on the state gazette, will be mandatory for all public officials. This document is called The North-East Sector Partial Urban Development Program [14], whose methodology in which urban simulation is included was also developed by the IMIP.

Characteristics The UGS is a Cellular Automata based build out scenario software. Cellular Automata are models in which contiguous or adjacent cells change their states trough the repetitive application of simple rules [3]. It has been recently applied to urban studies [24, 19] regarding prediction [16], expansion, growth and sprawl [1, 26, 15], shrinkage [7], land use change [4], transport

[2], spatial patterns [6], densification processes [18] and as a land use policy analysis tool [25]. The UGS is aimed towards a non-specialist user and does not require extensive supportive datasets generally unavailable or costly to collect. It works by first making a GIS Overlay operation that combines land use and environmental layers into one composite layer of developable lands and then, depending on inputs of estimated growth and growth management policies, applies a multiple selection criteria procedure to select specific new development locations from this developable lands (fig. 1). The GIS Overlay operation is performed in multiple steps between same pixels of all data layers resulting in a unique composite layer. Each data layer was converted to a matrix of binary values: 1 if a particular criterion was satisfied and 0 if not. Data layers were compared in sets of two by multiplying the same pixel. If the result was 1 it means that both criteria were satisfied (1x1=1), if the value was 0 it indicated that at least one of the criteria was not satisfied (1x0=0, 0x1=0, 0x0=0). Figure 2 shows the process in which land that is unoccupied, with gentle slope, no floodplains and no wetland is identified.

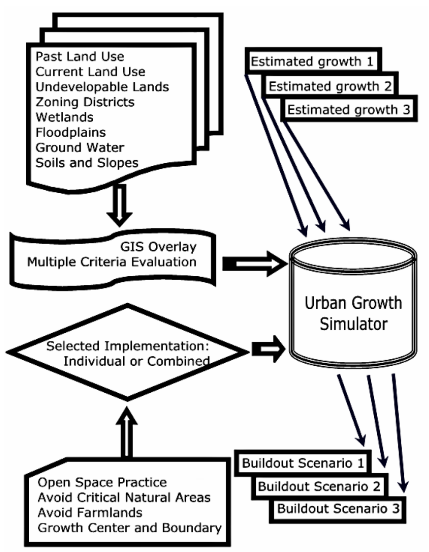

Fig. 1. figure
Simulation Process of the Urban Growth Simulator [17]

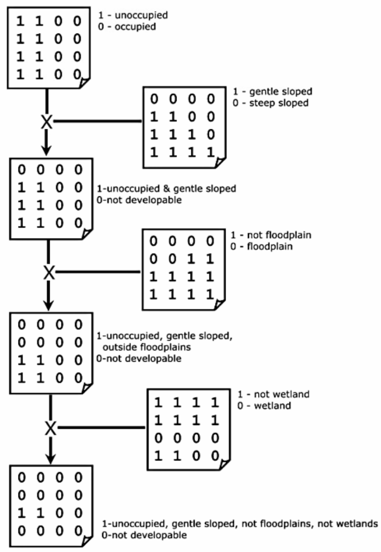

Fig. 2. figure
GIS Overlay Function Utilized by the Urban Growth Simulator [17]

As stated above, output scenarios depends on growth management policies, and this are the following:

Open space growth The surface that is being occupied is reduced to a percentage stablished by the user. This implies vertical growth so more natural area or open space is left without development.

Critical natural areas Urban growth is avoided in relevant natural areas like wetlands, floodplains, steep sloped areas, groundwater, and areas with endangered plants or animals.

Agricultural land Urban growth is avoided in agricultural lands.

Growth limits Urban growth is constrained inside a previously designated polygon.

To simulate urban growth, the UGS picks a location of developable land using a random-number generator and this site is checked for Availability: whether the site is occupied by a land use, Zone use: if the site is zoned for residential, commercial, industrial, tourism or mixed use, Boundary: if the site is within growth boundaries established by user and Location: if the site is within critical natural areas or farmland. If the site does not satisfy any of the above, it is abandoned and the UGS takes on another site at random. The process is repeated until all feasible projected growth has been realized.

Land uses that can be simulated are residential, commercial, industrial, touristic, mixed I and mixed II. Results are shown trough a map that shows current land uses and overlays new development over feasible areas for urbanization, and with a table that shows the projected development that is inputted by the user and the resulting development that was possible according to public policy implementation. It additionally shows the amount of agricultural land and natural areas that have been lost because of new development. A random factor prevails in all simulations so results differ from one run to another. The variety of results depend on the margin that exists on the way the territory can be occupied. Resulting tables can be saved in the spreadsheet format and maps in shp format.

Preparation 5 layers of information are needed and form the current territory state: land use, zoning, streets, critical natural area and water. These layers have to be prepared in a separated way in a GIS according to specific nomenclature.

Land use This layer is current land uses and must be visualized in two groups: developable and non-developable areas. The simulator establishes new growth over developable land. Non-developable areas can represent up to 11 current land uses and must specify if they are agricultural land or not.

Zoning This layer is based on the allowed land uses according to official urban development programs and represents the land uses permitted in zones marked as developable in the Land Use layer. Permitted land uses are residential with three density modalities, commercial, industrial, touristic, mixed I one and mixed II. The user can let the simulator randomly decide what land use can appear selecting a special use called without specific use.

Streets This layer represents streets infrastructure including major roads. The modeler must decide if only current infrastructure is inputted in the model or include future roads. This layer is taken into account when growth occurs along this infrastructure.

Critical natural area This layer represents all those areas that have a high environmental value like wetlands, patches of native vegetation, dunes and other natural characteristics.

Water As it name indicates it represents bodies of water like lakes, rivers, creeks and sea surfaces.

Once these 5 layers are inputted into the model the next step is to input growth projections for each land use. The amount of growth depends on whether one wants to represent the current growth tendency or if these projections represent deliberate efforts of growth promotion or inhibited control. If current growth tendency is chosen it must be estimated for each land use according to a methodology established by the modeler. Once the projections are established they must be distributed between cluster growth and/or along road infrastructure. Finally, minimum lot size is inputted. When these parameters are established, public policies that are desired to be simulated are selected and the simulator is ready to be used.

3 Scenario and databases

One of the latest urban planning instruments elaborated by the IMIP is the North-East Sector's Partial Urban Development Program [12] and the UGS has been used to test its zoning proposal to know what could be the resulting patterns of land occupation and impact on agricultural land and natural areas if growth projections could be accomplished under the implementation, or not, of certain public policies. The methodology consisted first on doing an exhaustive field survey to identify current land uses and also about street structure in a study area of over 6,000 ha. This information was translated to a digital elevation model in which intermittent streams where included as critical natural areas along with land with a slope higher than 35%, because local law does not permit urbanization on steeper slopes. Developable and non-developable land was identified trough a fitness model. According to this final model a zoning and street infrastructure proposal was made that would serve to future growth. Four scenarios where executed several times and results analyzed to find relevant information that could help evaluate the zoning proposal, and based on this evaluation make the necessary adjustments if results where contrary to the main goals of the Urban Development Program. Finally, an overlay map was made for each scenario as a result of overlapping all its outputs and a street light color coding was used for ease of interpretation: red where overlapping was higher and thus higher match between all scenario outputs, yellow for medium overlapping and green for lower overlapping areas. Projections were calculated as a continuation of the current tendency of population growth from time cuts of 1995, 2000, 2005 and 2010 obtained from the National Institute of Statistics and Geography. Due to the natural conditions that still prevail in great part of the area of application of the Urban Development Program, with important presence of creeks, riparian vegetation and agricultural lands, four simulation scenarios where established: public policy to avoid growth over critical natural areas, public policy to avoid growth over agricultural land, public policy to avoid growth both over critical natural areas and agricultural land and a scenario in which no public policy is applied.

4 Results

No public policy. In this scenario all of the projected land uses where feasible but at the cost of losing and average of 269.02 has of agricultural land and 1,202.98 has of critical natural areas. Of interest was to see that an undesirable leap frog development pattern appeared by concentrating new growth over agricultural land far from consolidated areas and with under-developed or vacant land in between (Figure 3) , suggesting that although in this scenario is feasible to accept all projected growth it is necessary to implement public policies that promote growth around consolidated areas and to enforce protection of agricultural land. As a follow up to this scenario, in its overlay map a high overlap area was identified over an important creek and adjacent to an urban area in consolidation, warning a high possibility of occupation of this critical natural area. Then one year later, in early 2015, a controversial residential and commercial project was promoted in the same high overlap area (Figure 4), but finally was not approved. As a result, now other high overlapping areas resulting from the simulation are being analyzed as to how to continually prevent its urbanization if located in other critical natural areas.

Avoid growth over critical natural areas. In this scenario each land use projection had different feasibility results, except for residential land use which was feasible in its entirety. As expected, prohibiting growth over critical natural areas had a major impact on agricultural land. If in the previous scenario in which 259.02 has where lost on average, in this one the loss was 438.98 has. Industrial was the most inhibited land use due to protection of natural areas, because this land use has very restrictive and limited locations in the evaluated zoning proposal. Consistently in all simulations only 30% of total projected use was possible. This suggest a strong conflict between this two uses and a high probability of natural area loss in the real world if law is not enforced in this manner. Except for residential land use, all projections of growth along streets where feasible, but not for cluster growth, showing a competition for land far from main roads. This could be because of low land cost, but the simulator does not take into account land value so further research is needed. Again, industrial and mix use were the most affected: the feasibility of cluster development oscillated only between 0 and 2% in all simulations for industrial and 10% for mix use. In comparison with

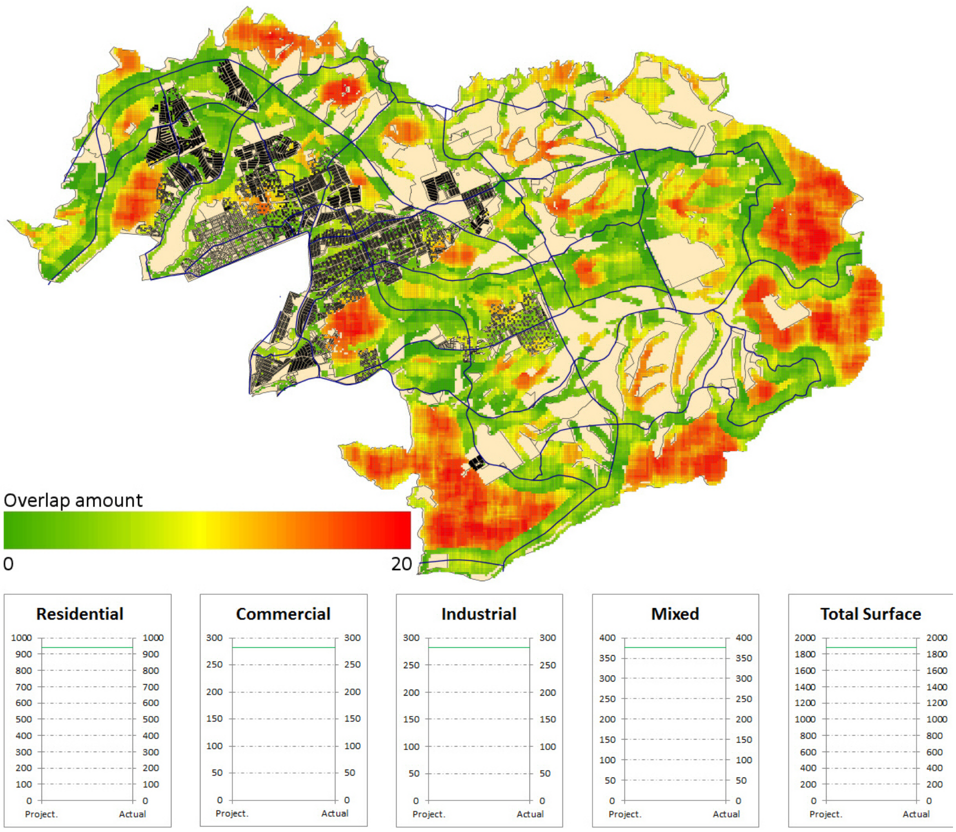

Fig. 3. Overlay map of all simulation results for the "No public policy" scenario, and comparative charts of projected vs. actual growth for land uses and total growth.

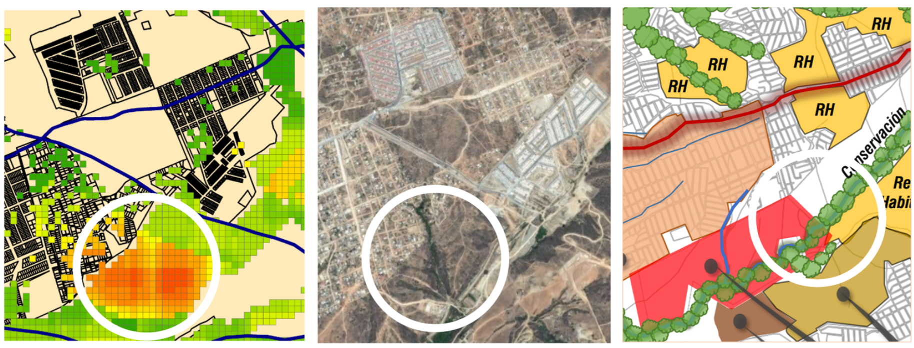

Fig. 4. Right: High overlap area of scenario. Center: Satellite image of area. Left: Part of promotional image of residential and commercial project, showed in red polygon.

the previous scenario, a high vacant lot occupancy is observed in consolidated areas and a wide urban strip that crosses along an east-west axis, with a high probability of growth over streams found inside it (Figure 5). This demands the application of policies that first promote growth inside and around consolidated areas to prevent sprawl.

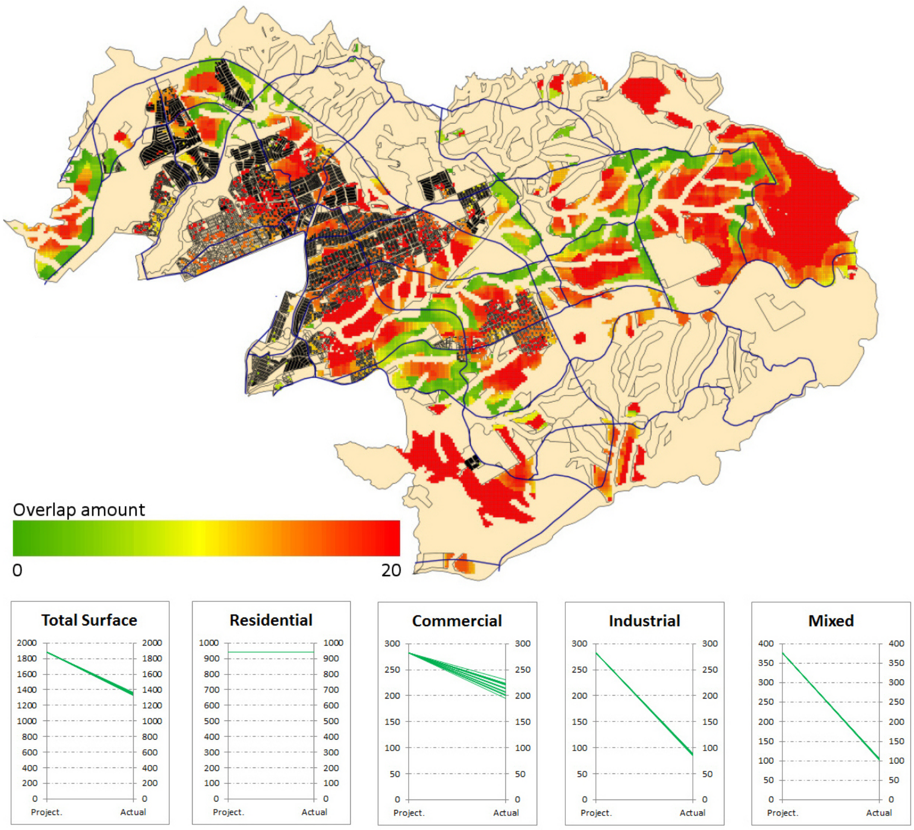

Fig. 5. Overlay map of all simulation results for the "Avoid growth over critical natural areas" scenario, and comparative charts of projected vs. actual growth for land uses and total growth.

Avoid growth over agricultural land. In this scenario all land use projections where feasible but at a cost of critical natural area loss, mainly creeks, with an average loss of 1,393.90 has. Even so, this feasibility must be revised carefully comparing it with real growth patterns because the resulting growth in the UGS had a branch-like configuration as it is accommodated strictly inside the creeks, something that complies with the inner logic of the UGS but far from reality, so this feasibility could be greatly reduced. In comparison with the previous scenario, the occupancy of vacant lots in consolidated areas is very low (Figure 6).

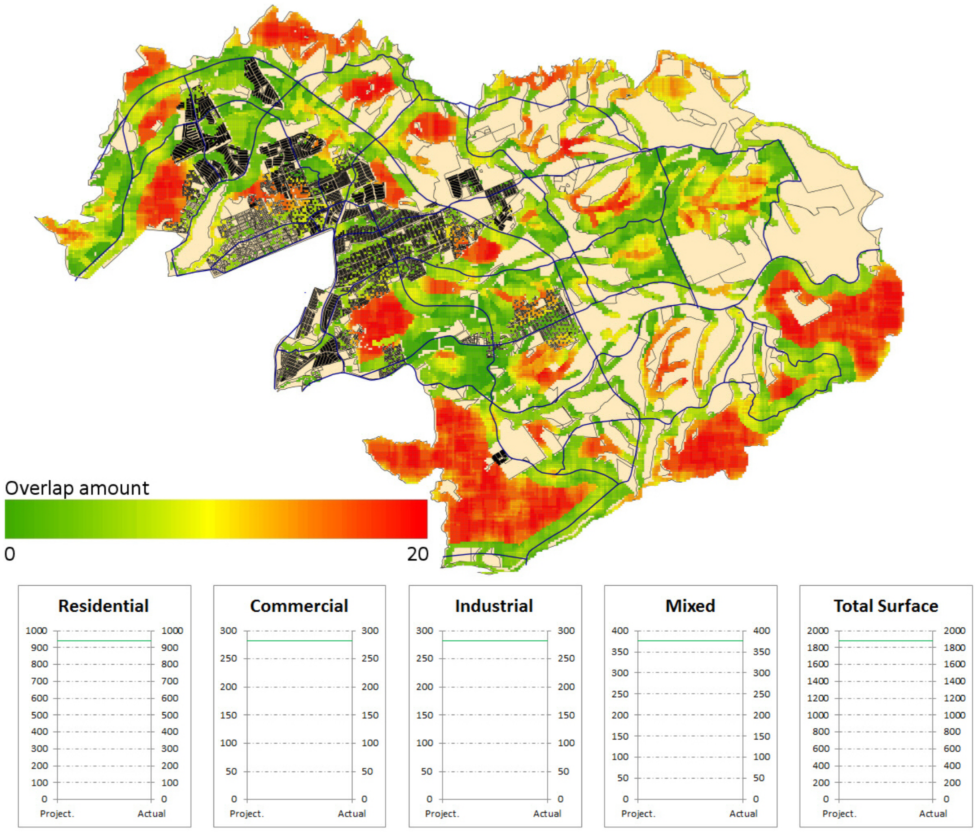

Fig. 6. Overlay map of all simulation results for the "Avoid growth over agricultural land" scenario, and comparative charts of projected vs. actual growth for land uses and total growth.

Avoid growth over critical natural areas and agricultural land. This more restrictive scenario has an impact over all the projections of land-use growth and in which none were feasible in its totality. A high concentration of growth is observed around consolidated areas and on its vacant lots, and an east-west growth pattern that crosses all the application area of the Urban Development Program (Figure 7) indicates that although there are restrictive policies about urban expansion there is still a high probability of urban sprawl. Like industrial use in the Avoid growth over critical natural areas, commercial use was greatly affected, feasible only along streets but none in a cluster fashion, so a conflict between commercial and agricultural activities are evident.

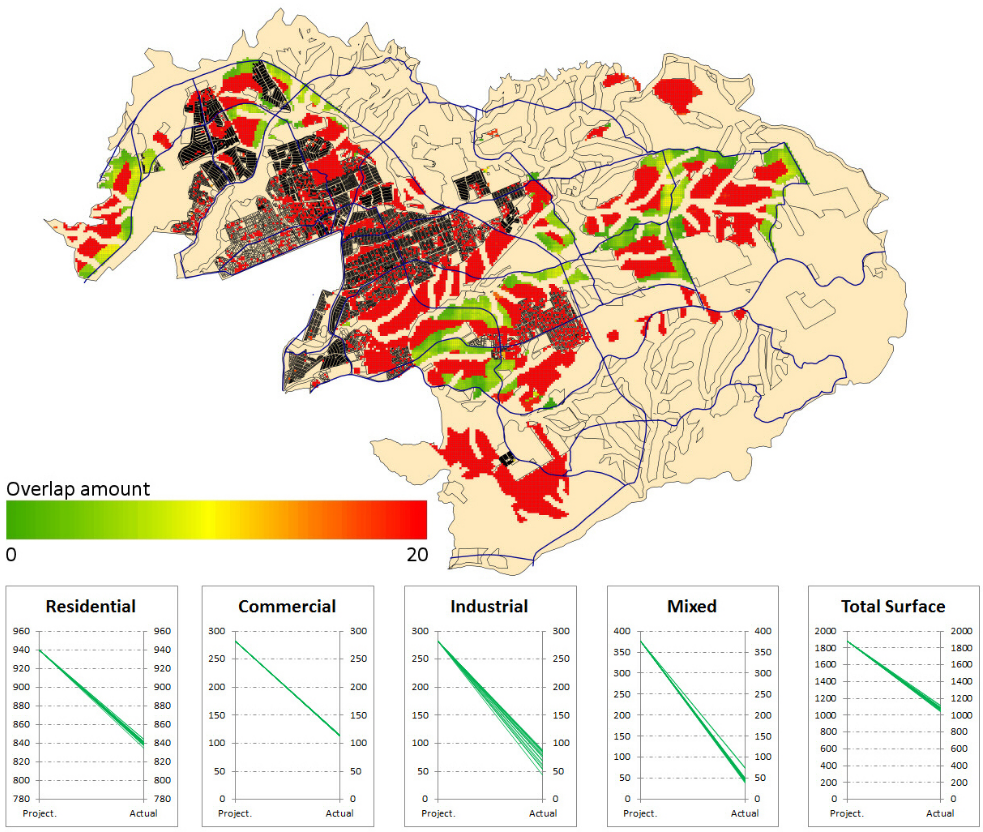

Fig. 7. Overlay map of all simulation results for the "Avoid growth over critical natural areas and agricultural land" scenario, and comparative charts of projected vs. actual growth for land uses and total growth.

4.1 Implementation of simulation results

The UGS showed unexpected results that merited revision of the zoning proposal of the Urban Development Program, particularly due to conflict observed between growth projections and insufficient availability of land, and between land uses and protection policies, having to think again the general strategy of land occupation, including the use of higher densities and earlier use of land reserves that where contemplated farther in time. It was also observed that the same Program induced sprawl patterns contrary to what it supposedly trying to avoid.

This has led to a reconfiguration of the general strategy of urban development that is currently under work.

5 Conclusions and future work

The use of the UGS has been satisfactory in a way that it fulfills its objective of a useful tool for the design of public policies of urban development and has set a good precedent for its continued use but also also for it's improvement. Despite its benefits, it is necessary to observe a series of situations that can be seen as constraints in its application but can also as future work to be done. First, its use is going to depend on the availability of trustable information for growth projections and for making the necessary layers of information that have been mentioned earlier. Another issue is the availability of specialized technicians that are needed and must be familiar with GIS tools. As a counterpart of its ease of use by people that are not specialized in the field of urban planning, is that the user must have strong interpretation capabilities if he wants the UGS to be used more as a planning tool rather than a simple software of communication. User must also be aware that a random factor is involved in the generation of simulation results so each of them must be seen as one out of many possible futures so to avoid to take them literally. Future work is aimed at fulfilling three objectives that is expected to have more realistic simulations: capacity to accept more layers of information, more policies and to behave according to specific occupation rules. Among the new layers are related to land: price, type of ownership, territorial conflicts and transport and public services coverage because they all severely constrain current city development; among new policies to be simulated are regulation of occupation on steep slopes, type of development according to land cost, and preference of urbanization according to level of public services coverage. But most important will be the implementation of rules about the occupancy of the territory by new development so it can take into account aspects like proximity to current activities, road networks, compatibility, attraction and conflict between land uses, and its corresponding occupation preferences.

Even so, it has been observed that the UGS has a high value due to its simplicity of use for a non specialized audience, by showing them the probable future that may arise and that cannot be foreseen due to the complex spatial interactions of even a reduced set of variables. For this reason, the UGS must be improved and used as part of a set of tools for the design of public policies in more Urban Development Programs done by the IMIP.

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