The Xplorah SDSS

Supporting integrated planning on the island of Puerto Rico

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Key words: Decision Support Systems, Model integration, Bridging the science-policy gap

Abstract: The Xplorah system is a tailor made Spatial Decision Support System (SDSS) for the three major islands of Puerto Rico. It has the aim to assess the impact of a wide range of scenarios on policy-relevant indicators by simulating future developments in the region over a time span of 20 to 30 years. The application encompasses a set of dynamically linked models working at different scales and incorporating knowledge from numerous disciplines. Changes take place under influence of three types of drivers: external drivers such as worldwide economic developments, policy drivers such as infrastructure planning, and the behaviour of actors as defined in model parameters. A very important policy driver for land use change is spatial planning. As a result of user feedback a dedicated zoning tool has been developed to enhance the introduction and use of spatial plans in Xplorah. This tool forms an integral part of the system. A user can introduce plans for the entire three islands or only parts of it, which facilitates the assessment of local plans in the island wide dynamics. The influence of spatial planning is computed in run-time, based on the activation or deactivation of spatial plans as well as the existing land use at that time. This paper briefly describes Xplorah as an integrated SDSS and elaborates on the introduction and use of spatial plans in the system. We discuss how user interaction has enhanced the usefulness and usability of the system and demonstrate the use of the new zoning tool with a practical example for developing a new master plan for Puerto Rico.

1. INTRODUCTION

Today's world is increasingly more complex and changing rapidly. Numerous processes operating at different spatial and temporal scales act and react upon each other, making it difficult to understand and assess the impact of interventions on the human-environment system. Nonetheless, planners and policy makers face the challenge of making decisions in this complex system. They are not only confronted by interventions in their own sector, but must think about the impact of interventions in all sectors as well as a range of external factors not directly influenced by policy interventions, such as climate change and global socio-economic developments.

Integrated spatial models, comprising of several components representing different processes, can support the policy practice in understanding the (unexpected and often unwanted) side effects of policies as well as the trade offs that need to be made and win-win situations that can be created. To enable this type of analysis, the integrated model should allow for feedbacks between the model components to ensure a truly dynamic integration resembling real-world interaction between these processes. Furthermore, such models should incorporate both socio-economic and bio-physical components and ensure proper linkages to the policies at stake and the indicators relevant for policy making (Van Delden et al., 2007; Volk et al., in press).

One of the most influential policy domains that can be tested using an integrated spatial model is spatial planning. Spatial planning is an activity that takes places at different scales, from local city planning to national land use plans. As these spatial plans influence each other as well as other processes, they require an integrated system for the analysis of their effects. In addition, spatial plans come in a rich variety. Some are strictly enforced, other less so. Some impose restrictions, while others actively stimulate developments. Moreover, not all plans are continuously valid as they can be activated in time, or stopped any time later.

In this paper we will present an integrated model, Xplorah, which is developed with the aim to support the Puerto Rican policy practice. It has been developed in an interactive and iterative process together with the intended users, Puerto Rico's Planning Board and the local municipalities. The model links processes operating at various spatial scales, such as macro-economic behaviour, the evolution of the population on the island, the interaction between the various municipalities and the local dynamics. Xplorah is equipped with several policy levers that impact on the model at the relevant scale of the policies. The system subsequently provides results in the form of social, economic, transport and environmental indicators at the spatial levels asked for by the users. In this paper we focus on one of the major enhancements that was made based on user interaction: the development of a zoning tool to support spatial planning in Puerto Rico. This zoning tool allows introducing and interpreting spatial plans on all scales individually, without much processing. We will explain how the tool operates and demonstrate its applicability by showing a practical example for future residential development in the coastal zone.

2. USER FEEDBACK IN THE DEVELOPMENT PROCESS

The Xplorah SDSS has been developed in an iterative process in which three main parties were involved: users, scientists and IT specialists (Figure 1). At the end of each iteration round a new prototype is presented to the users to communicate progress and to obtain feedback. More insight in the development process of the Xplorah SDSS and decision support systems in general can be found in Van Delden et al. (in press).

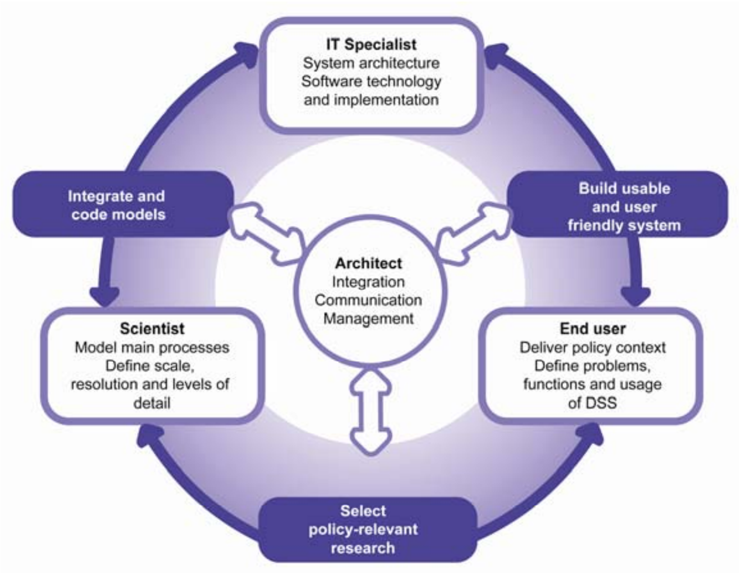

Figure 1: Iterative and interactive DSS development process (Van Delden et al., in press)

The system is currently being implemented at Puerto Rico's Planning Board and a selected municipality as part of the implementation phase. A group of some 50 staff members, ranging from technicians to executives, have undergone a training course of over 150 contact hours to familiarize themselves with the system. Still, expert status will be achieved only through continuous use of the system as it becomes operational. In this process, it is a challenge to create awareness not only on the capabilities of the system, but also on its limitations.

During this implementation phase, the system is subjected to evaluation on its capabilities for and applicability to the Puerto Rico Planning Board's functions, context, and decision making practices. One of the aspects identified through this process was the potential of the system to support the development of the new master plan for the island, a process in which the Planning Board needs to coordinate demographic, economic and spatial developments together with the 78 municipalities on the island.

While presenting the functionalities of Xplorah, it quickly became apparent that the way zoning regulations were included needed updating to better meet the actual practice. In earlier versions, the zoning regulations worked as a yes/no option indicating at what locations developments of specific land use functions would be allowed or not, and permitted changing zoning rules at only two different future points in time. To be useful for the Puerto Rican planning practice, it was requested to include more flexibility in the interpretation of the plans by allowing restrictions to be enforced strictly or weakly, actively stimulating certain developments and ranking spatial plans in order of importance (which plans overrule which plans). Furthermore, it was identified that the 78 municipalities on the island all make their specific spatial plans which are approved at different points in time and hence have different start and end years.

To meet the above requirements a zoning tool was developed that operates as an integral part of Xplorah. In the next section we explain how spatial plans impact the model, followed by a description of the zoning tool in section 4 and example of its use in section 5.

3. THE INTEGRATED MODEL

The Xplorah SDSS encompasses an integrated set of dynamically linked models working at different scales and incorporating knowledge from numerous disciplines (Figure 2). These models simulate activities that take place at four scales represented by the four levels of the integrated model: global, national, regional, and local.

At the *global* level, Xplorah uses climate change scenarios that feed to the macroeconomic model. Hence, climate change is not simulated, but the system offers the opportunity to test hypotheses through a set of linked equations in a relative straightforward way. The relations in the climate component express the effect of temperature change, through precipitation and storm frequency, on the national agricultural production, the national demand for tourism and the construction required on the three islands.

At the *national* level Xplorah includes a macroeconomic model and an age-cohort model. Macroeconomic activities are modelled by means of an econometric model (Gutiérrez, 2007) that can be updated or changed by the user. The econometric model receives input from the climate component and the age-cohort model and generates forecasts for the demand and GDP for each of the five aggregated economic sectors: agriculture, construction and mining, manufacturing, trade and services, and public services. Demands are expressed as a number of jobs per economic sector that is later distributed over the municipalities.

The age-cohort model generates the national demographic structure on a yearly basis. The model computes population figures for all ages and both sexes. This model incorporates legal and illegal immigration flows and provides information on the labour force supply, which is used in the macroeconomic model. Economic conditions, in turn, have an impact on migration and mortality rates. Policy options at the highest spatial level include government consumption, public investment, migration policies and birth control incentives.

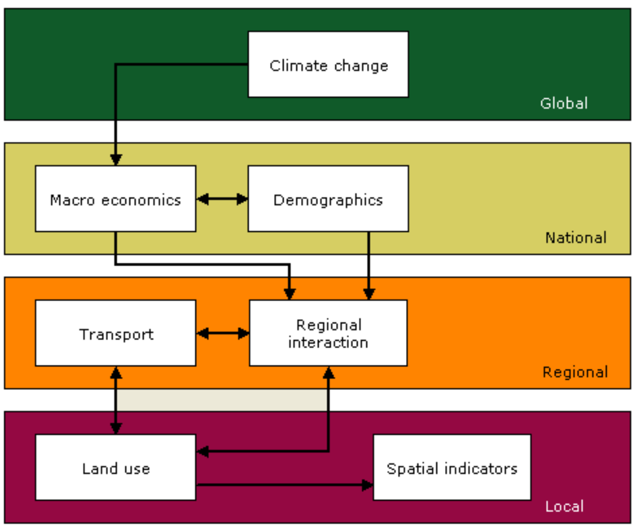

Figure 2: Model components at the various levels of the integrated model. Arrows indicate the flow of information from one model component to the next.

At the *regional* level three model components are incorporated: a spatial interaction model that distributes national totals for population and jobs over the municipalities, a transport model that simulates congestion and travel times between the different transport analysis zones, and a land use demand component that converts the regional levels of activity in different socioeconomic sectors to land use demands for the local land use model.

At the regional level, Puerto Rico is subdivided into 78 regions that correspond to the municipalities on the island. The model distributes national totals for population and jobs in each of the five economic sectors over the municipalities based on migration and distribution of national growth. Migration and distribution are computed based on the relative attractiveness of each region using a spatial interaction model or gravity based model (Fotheringham and O'Kelly, 1989; Fotheringham et al., 2000).

The population and numbers of jobs per region computed by the spatial interaction model are subsequently converted into a number of cells that needs to be allocated. This conversion is done using the cell productivity, which expresses the amount of a specific activity that is located in one cell. Cell productivity is computed as an average for each municipality separately. For land uses that do not have an activity associated with them, such as forests and wetlands, the area demand per municipality is a direct input to the model.

The measure of distance that is used in the spatial interaction model is very important. In fact, it is the determining factor of this model for the accuracy with which migration flows can be modelled. It is known from literature (see e.g., Fotheringham, et al., 2000) that Euclidian distances are a relatively inappropriate measure of distance for modelling activity migration. Since simulated travel times provide much better results, Xplorah includes a transport model that calculates travel times explicitly, based on activities, travel behaviour and the road network. This transport model is based on a classical four step approach: production-attraction, distribution, modal split, and assignment (see e.g., Ortuzar and Willumsen, 1994). For the transport model Puerto Rico is subdivided in transport analysis zones. These zones are equal to or smaller than municipalities, depending on the amount of activity within a zone. Trip origins and destinations are generated from the number of inhabitants, jobs and the area of other land uses per transport zone. From this Xplorah calculates travel times between zones and between regions, but also congestion on the transport network and a number of indicators. Main policy options at regional level are options related to transport: pricing of public transport, toll costs and parking costs.

At the *local* level, Puerto Rico is represented as a grid with cells that show the predominant land use on that location. Changes in land use are driven by demands per land use, as computed on the regional level. Land uses are allocated using a constrained cellular automata (CA) model (White and Engelen, 1993; 2000). This allocation procedure considers several factors that determine land use dynamics. These are local accessibility, physical suitability, zoning regulations, the attraction and repulsion between neighbouring land uses and a stochastic perturbation term. The exact allocation procedure is further elaborated in the next section. Grid cells on the lattice represent an area of 240 by 240 meters. This resolution is sufficient to study land use dynamics for the whole island. However, for studies that focus on smaller regions, a 240 meter resolution was not found appropriate by local planners. Therefore, we simulate land use changes for the municipality of interest at a 60 meter resolution. In all other aspects this municipality is treated similar to the remaining 77 municipalities. Important policy options included at local level relate to road construction and spatial planning.

The local bio-physical and socio-economic characteristics finally feed back to the attractiveness at the regional level. The Xplorah system thus aims to integrate important processes and feedback loops for the assessment of land use changes. More information on the integrated model can be found in Van Delden et al. (2008) and RIKS (2009a).

4. IMPROVED SUPPORT FOR SPATIAL PLANNING

Spatial planning impacts on the land use allocation at local level. Land uses are allocated on those locations that have the highest transition potential for this land use. The transition potential at time *t* for land use function *f* in cell *c* (${}^{t}P_{f,c}$) is calculated using the following equation:

$$ {}^{t}P_{f,c} = {}^{t}N_{f,c} \cdot {}^{t}v_{c} \cdot {}^{t}S_{f,c} \cdot {}^{t}Z_{f,c}\, {}^{t}A_{f,c} $$

The transition potential is a multiplication of the neighbourhood potential (${}^{t}N_{f,c}$), the suitability ($S_{f,c}$), the zoning (${}^{t}Z_{f,c}$), the accessibility (${}^{t}A_{f,c}$) and a stochastic perturbation term (v_c). For an elaborate explanation of the local land use allocation including this equation we refer to RIKS (2009a). For the current paper we will focus only on the zoning element of this equation. In the first Xplorah prototypes zoning regulations worked as a yes/no option indicating at what locations developments of land use functions would be allowed or not. In the model ‘allowed’ and ‘not allowed’ were converted into the values ‘1’ and ‘0’, where ‘0’ results in a transition potential of ‘0’ indicating that the location will not be occupied by the land use at stake. To allow for planning over time, users could open up locations for land use functions from two different planning periods onwards (Engelen et al, 2003; RIKS, 2009b). This zoning status was indicated by one zoning map per land use function. These zoning maps were the result of pre-processing spatial planning documents outside the Xplorah SDSS.

The reality of spatial planning however is much richer than simply the indication whether a specific land use development is allowed or not. To be useful for the Puerto Rican planning practice, users requested to include more flexibility in the interpretation of the plans by allowing restrictions to be enforced stricter or weaker, stimulating certain developments and ranking spatial plans in order of importance. Furthermore, it was identified that the 78 municipalities on the island all make their own spatial plans which are approved at different points in time and hence have different start and end years. Finally, it became clear during the training courses that many participants experienced difficulties when working with different applications for preparing maps and running the simulation.

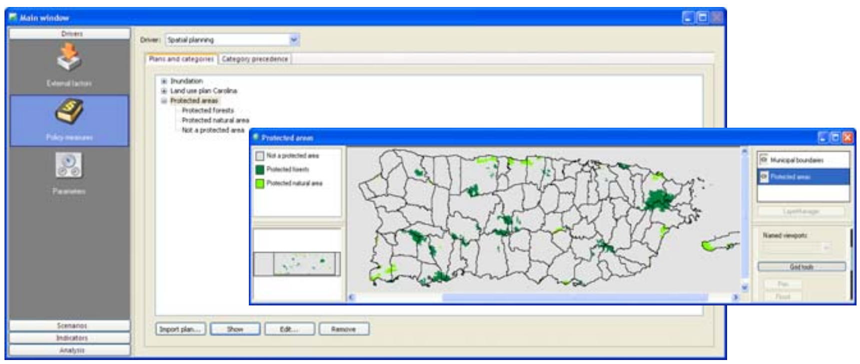

Figure 3: Importing spatial plans in Xplorah.

To accommodate user requests, Xplorah now includes an enhanced way of dealing with spatial planning. It incorporates a zoning tool that works as follows: In its initial screen named 'Plans and categories' a user is able to upload all spatial plans relevant for the application. The term plan refers to en entire map representing for example the protected areas, and the term category to any class that can be found on this map, such as protected forests. Maps can be introduced in data formats from common GIS packages. Moreover, municipalities can provide their spatial plans at municipal level, without needing to provide information for the rest of the island. As can be seen in Figure 3, Xplorah currently contains plans for protected areas and inundation zones for the entire island and a land use plan for the municipality Carolina.

In a second step the user can interpret the categories on these plans for each land use separately (high density residential in the given example).

Interpretations are made on the zoning status, enforcement, start time and end time (Figure 4). Contrary to the original allowed/not allowed status, the new zoning tool also allows to set the zoning status to ‘actively stimulated’, which is relevant for e.g. planned urban expansion zones. In order to accommodate that some plans overrule others, the order of the categories on the plans represents a hierarchy. The category that is ranked highest will overrule the lower ones in case of conflict. The precedence of the categories can be set for each land use separately. The enforcement of restrictions is identified by the horizontal line that divides between weak enforcement and strict enforcement. Categories with a zoning status ‘restricted’ that are placed above the line are those that are strictly enforced, categories below the line are weakly enforced. Hence, we assume that plans that are higher in the hierarchy will inherently be enforced more strictly. Finally, a user can enter the start and end date of the planning regulation. This meets the requirement to have municipal plans start in the year they are approved. The explicit indication of start and end times allows the introduction and ending of restrictions or facilitations at any point in the simulation. In the current example we have included a start date for the municipal plan of Carolina of 2012.

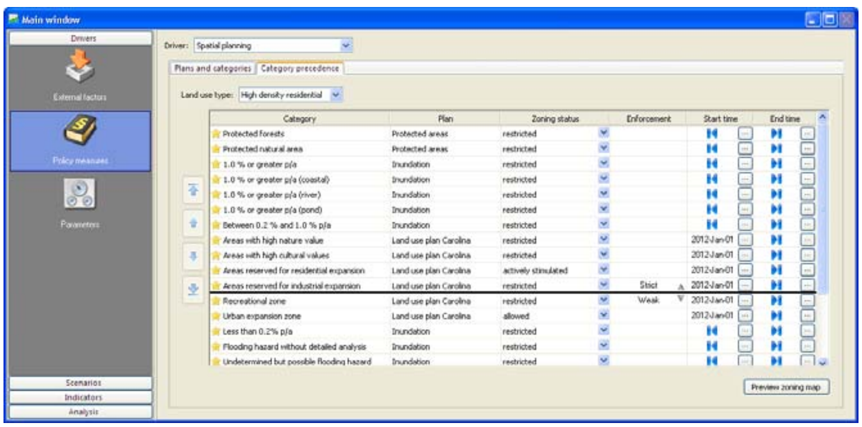

Figure 4: Interpreting spatial plans in the zoning tool. The example shows the interpretation for high density residential development.

The resulting zoning map for high density residential development is shown in Figure 5. The map shows the zoning status for 2006. Protected areas and areas with a high flood risk are strictly prohibited for further development, while most of the interior of the island is not supposed to become urban, but restrictions are expected to be weaker enforced. Existing urban areas are allowed to become denser and new high density urban development is also allowed in the designated urban development zones. The planned developments in Carolina municipality are not yet included in this map as they start in 2012.

The third step is the conversion of this categorical zoning map into numerical values that can be used in the computation of the transition potential. For this conversion, the four zoning categories need to be given a numerical value. The user is can set these values through the graphical user interface with the following limitations: the value for strictly restricted is ‘0’, the value for weakly restricted lies between ‘0’ and ‘1’, the value for allowed is ‘1’ and the value for actively stimulated is higher than ‘1’. In the given example strictly restricted is set at 0.5 and actively stimulated at 1.2.

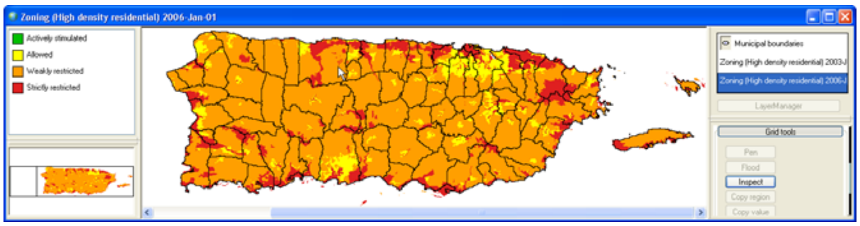

Figure 5: Result map of zoning regulations for high density residential development for the year 2006.

However, when new plans are introduced over time, they might actually prohibit the land developments that took place earlier during the simulation. To avoid that existing developments are removed as a consequence of the introduction of new restriction, the influence of spatial planning is computed in run-time, considering the actual land use at the time of introduction. This allows existing developments to remain at a location even when newly introduced plans prohibit so.

5. PRACTICAL EXAMPLE

As part of the training exercises carried out during the implementation of the Xplorah SDSS at the Puerto Rican Planning Board and Carolina municipality, we have tested the new zoning tool on an urban planning example. As Puerto Rico is a densely populated group of islands, the coastal zones experience a high pressure from urban development. However, these same coastal zones are at certain locations prone to flooding and at other locations protected because of their high nature value. Because planning is often lacking or weakly enforced, new urban developments appear all around the existing cities and main roads, causing uncontrolled urban sprawl.

Puerto Rico is currently developing a national land use plan to provide direction to the growing urbanization. The aim of this plan is to ensure a sustainable future in which economic prosperity, social well-being and environmental protection are highly valued. Because of its integrated nature, Xplorah can very well provide support to the development of such a plan and hence we developed a training exercise to support the master planning of the island. The socio-economic models provide the expected growth in activities per municipality, while the local land use model takes care of its allocation. This allocation was restricted by including a protected areas map, a map with areas prone to flooding, a national land use plan and municipal plans in the system.

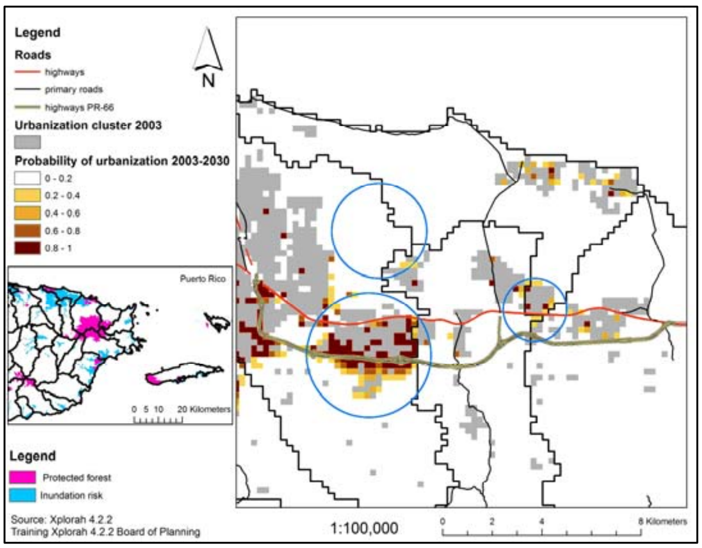

Figure 6: Probability of urban development over the period 2003-2030 in the area east of San Juan without a land use plan.

The exercise consisted of a simulation run without the national land use plan and a run with the national land use plan to investigate the impact such a plan would have on the urban development. As Xplorah includes a stochastic component we needed to run the model a number of times to understand the variation this component brings to the future land use. In the current example we have run each simulation 10 times and based on this we have developed probability maps for various urban land uses over the period 2003-2030. Figures 6 and 7 show an area east of the capital San Juan, which includes the municipality Carolina. It shows the probability for the land to become urbanized over the course of the simulation. Urban land is the combination of four land use classes that include both residential and commercial activities, and which are aggregated here for purposes of illustration.

On the map we find the location of the newly developed highway PR-66 and to the left of this map we see a smaller map with the protected forests and flood zones. Comparing the result maps for this area we find that without a land use plan the area around the highway is very likely to convert into urban land. However, this area closely borders the El Yunque rainforest, and therefore the land use plan restricts urban developments in that area. Figure 7 therefore shows that restricting land developments in one location will probably cause urbanization in another close-by location (indicated in the uppermost circle). Looking at the new location is more detail we find that this location is of interest and allowed for development because it is not prone to flood risk, in contrary to the surrounding locations. This first example shows that there are two sides on the protection of forests, as it will probably lead to other urban developments.

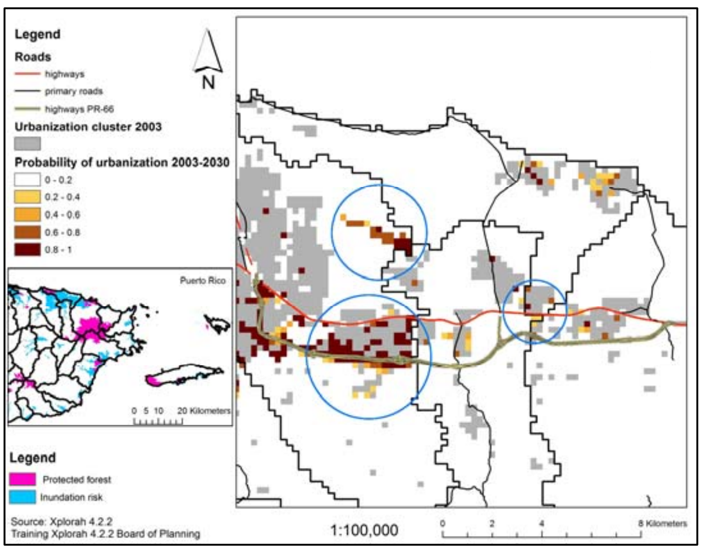

Figure 7: Probability of urban development over the period 2003-2030 in the area east of San Juan with a land use plan

A second example shows the result maps of the area around Ponce on the south of the island (Figures 8 and 9). It shows that urban sprawl appears on the outskirts of the city in the alternative without a land use plan, while the introduction of the land use plan shows an infill in the city centre.

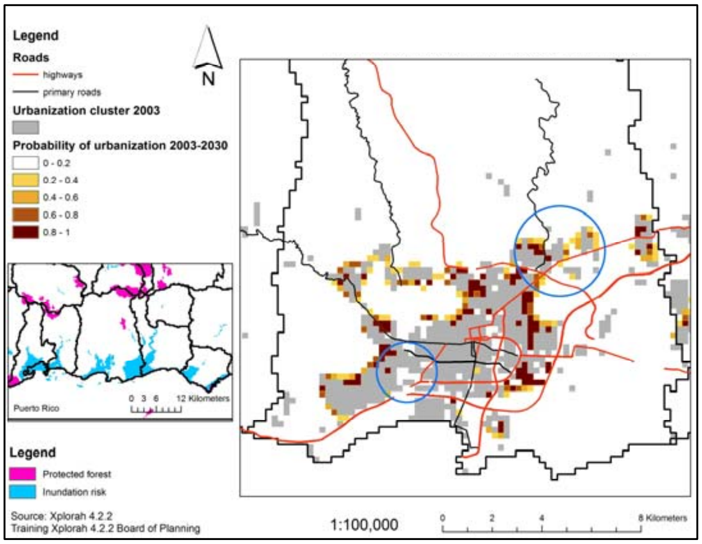

Figure 8: Probability of urban development over the period 2003-2030 in the area around Ponce without a land use plan.

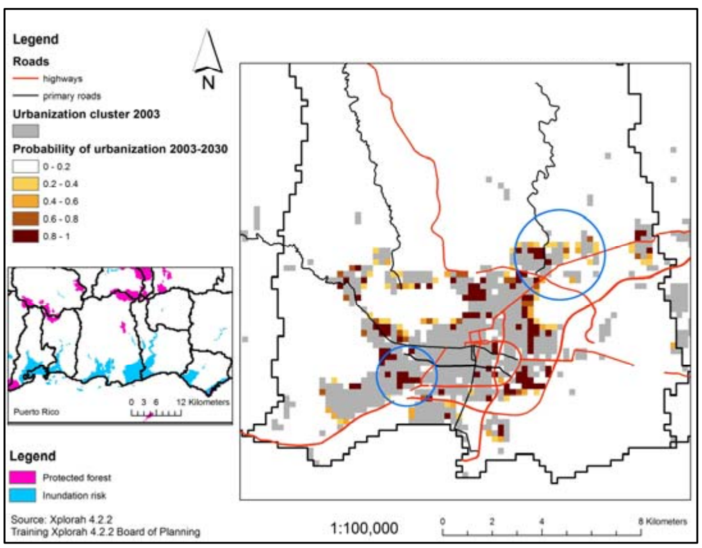

Figure 9: Probability of urban development over the period 2003-2030 in the area around Ponce with a land use plan.

Various spatial configurations cause different mobility patterns and hence results in different intensities of the network. As Xplorah includes a transport model these impacts are included during each simulation run. Moreover impacts of a new or upgraded highway have direct impacts on the regional attractiveness and the land use developments through the time it takes to travel from one municipality to the next and the local accessibility. The impact of the reciprocal effect between land use and transport was most clearly shown in the example near San Juan where new urban developments along the new highway in turn cause a higher intensity and congestion on this highway.

Finally, Xplorah is equipped with a number of socio-economic and environmental indicators that show the impact of a specific spatial configuration on e.g. habitat fragmentation and the access to recreational locations from particular residential locations.

6. CONCLUSIONS

The integrated nature of systems like Xplorah makes it possible to investigate the impact of actions in one discipline, such as spatial planning, on other disciplines, such as the environment of the (local) economy. Moreover feedback loops between models allow to understand the reciprocal nature between interacting processes.

The current version of Xplorah enhanced both the user-friendliness and usability of the system, based on feedback from users. This has resulted in the incorporation of a zoning tool in the Xplorah SDSS which makes it easier to incorporate new plans, provides flexibility in interpreting them and increases the transparency of the system. To relate as much as possible to the actual planning practice the zoning tool allows the introduction of plans from different scales and a flexible interpretation of plans that can either prohibit or stimulate land use developments at specific locations. Furthermore, the tool offers users the possibility to rank plans according to their precedence and to set a start and end year of a plan, so plans can be introduced in the simulation whenever they are accepted.

This paper illustrates that user interaction has been crucial in the development of the Xplorah SDSS. As the system is currently being implemented and being evaluated we expect to receive more valuable feedback in the future. This will lead to a more usable tool that closer resembles the needs of planners in general and Puerto Rican policy makers in particular.

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